MIT Technology Review

VOL. 121 NO. 1 JANUARY/FEBRUARY 2018 US $6.99/CAN $7.99

GMO

Can gene editing delete the fear of GMOs? p. 30

DISPLAY UNTIL 03/5/2018

$6.99US $7.99CAN

02

0 74470 01308 2

We made phones smart.

Now, we're
making cities smart.
And medicine smart.
And homes smart.

From the Editor

Gene Editing Could Rewrite the GMO Debate

David Rotman is editor of **MIT Technology Review.**

Decades of fretting over the safety and virtue of genetically modified organisms have led to a perverse outcome. Plant scientists in academia and startup companies have largely shied away from creating new GM crop varieties because it takes, on average, more than a hundred million dollars and over a decade to get such a plant approved by regulators in the United States, and also because the idea of GMO food has elicited public outrage. As a result, a few large agricultural and chemical producers like Monsanto—or MonSatan, if you prefer—dominate the GM industry, making a killing off herbicide- and insect-resistant corn and soybeans.

The outcome has been just what GMO critics most dreaded: many farmers depend on a few large companies, whose researchers focus on traits designed to improve profits rather than produce healthier foods for consumers. For noncorporate researchers, meanwhile, genetic engineering of plants has been expensive and risky. That stunts progress in plant breeding just as climate change and population growth are putting growing pressure on agriculture (see "Why We Will Need Genetically Modified Foods," January/February 2014).

That's why the work described in "These Are Not Your Father's GMOs" (page 30), by our senior biomedicine editor, Antonio Regalado, is so important. Regalado explains how a leading plant geneticist is using gene editing to create a healthier soybean that farmers in South Dakota and elsewhere are beginning to plant and harvest. New gene-editing tools, either CRISPR or the slightly older TALEN, don't insert a foreign gene into the plant to create a new trait (as typically happens with conventional GMOs) but, rather, tweak the plant's existing DNA. The engineered crops thus sidestep the lengthy regulatory process and could avoid the stigmas surrounding GMOs entirely.

Gene editing is cheap, powerful, and precise. Most important, it puts many more plant scientists back in the game of creating new varieties of crops, dreaming up blight-resistant potatoes, tastier tomatoes, drought-tolerant rice, and higher-fiber wheat. Until now, there has been little progress in commercializing such agricultural innovations, which are likely to represent far smaller and less lucrative markets than herbicide-resistant corn and soybeans. Getting gene editing into the hands of a far larger group of scientists could return us to the original vision for genetic engineering as an invaluable tool for growing healthier and cheaper foods, helping to feed the world's growing population.

Or will it? That depends on public perception. Will gene editing be viewed as a state-of-the-art tool for improving crops, or an easier and faster way to create frankenfoods? One can only hope it's the former, and that plant science can fully enter the modern age of genomics, leaving fears of GMOs and MonSatan in the shadows.

ROXANA PERDUE

ALWAYS CHARGED.
ALWAYS READY.

THE LEXUS HYBRID LINE

DISCOVER THE POWER OF INNOVATION.

Every breakthrough drives us forward. Like regenerative-braking technology, which increases efficiency and boosts performance. So even when braking, you're creating the power to leap forward. With a range of advanced hybrid models to choose from and over a million hybrids on the road today, Lexus continues electrifying the way forward.

LEXUS
EXPERIENCE AMAZING

lexus.com/hybrid | #LexusHybrid

January/February 2018

This page: Eric Leuthardt drillls a hole into a patient's skull (p. 44).

WHITTEN SABBATINI


LIBERATE YOUR DATA. INNOVATE WITHOUT LIMITS.
Amazing apps need a powerful data platform – discover the world's first Engagement Database.
PRESS GO
www.couchbase.com/MITtech
Couchbase
START A REVOLUTION

CUSTOMER SERVICE AND SUBSCRIPTION INQUIRIES

National
800-877-5230

International
903-636-1115

E-mail
customer_service@mittechnologyreview.info

Web
www.technologyreview.com/customerservice

MIT Records (alums only)
617-253-8270

Reprints
techreview@wrightsmedia.com
877-652-5295

Licensing and permissions
licensing@technologyreview.com

Technology Review
One Main Street, 13th Floor
Cambridge, MA 02142
Tel: 617-475-8000

The mission of *MIT Technology Review* is to equip its audiences with the intelligence to understand and contribute to a world shaped by technology.

Technology Review, Inc., is an independent nonprofit 501(c)(3) corporation wholly owned by MIT; the views expressed in our publications and at our events are not always shared by the Institute.


MIT Technology Review
EmTech DIGITAL
Artificial intelligence is changing every business.
Don't be left behind.
March 26-27, 2018
St. Regis Hotel
San Francisco, CA
Register Today:
technologyreview.com/aiexperience

Views

INNOVATION

What I Learned from the People Who Built the Atom Bomb

Technologists want their creations to do good for the world. We should make it easier for them to accomplish that.

When I began my career in elementary particle physics, the great figures who taught and inspired me had been part of the Manhattan Project generation that developed the atomic bomb. They were proud to have created a "disruptive" technology that ended World War II and deterred a third world war through more than 50 years of tense East-West standoff. They were also proud to have made nuclear power possible. But their understanding of the underlying technology also gave them a deep regard for the awesome, unavoidable risks that came with those technologies.

As a consequence, they dedicated themselves to inventing, in parallel, the technologies behind arms control (like reconnaissance satellites to verify agreements) and nuclear reactor safety (like containment vessels for radioactive leakages). By working on both the bright opportunities and the complex quandaries of nuclear technology, these scientists tried to round out its effect on humanity. They recognized that the advance of knowledge is inevitable, but it needs to be steered in the direction of public good.

Technologists in my generation understood that we had an opportunity—and an obligation—to use our knowledge in the service of civic life and public purpose. It's obvious that technologists today have the same obligation, and also that society is in need of practical, analytically driven solutions to the problems that arise in connection with fast-paced technological change. Such solutions will emerge only if the new generation of young tech innovators is encouraged and inspired to assume the civic responsibilities that come with creating changes of great consequence.

There haven't been many technologists who became secretary of defense. But for me, there was a direct cause-and-effect relationship between my training in physics and the responsibilities of that job. Earlier in my career I worked on defense issues—of great consequence at the time—that had a strong technical component. One was evaluating President Reagan's idea of space-based defense against missiles, a.k.a. Star Wars, for the Pentagon (I concluded that it wouldn't work). Another task I took on, first in academia and then in a second job in the Pentagon during the Clinton administration, was controlling the nuclear weapons of the Soviet Union when that country disintegrated at the end of the Cold War (an effort that fortunately did work).

Young technologists I've met know that if they don't join the effort, choices will be made by politicians or judges who might not have much technical background or insight.

I had the satisfaction of knowing that better paths were taken because my technical knowledge contributed to decisions. Big issues and a chance to see your training make a difference are a powerful combination for a young scientist. I felt that strong attraction from the start, and in the years ahead I returned again and again to Pentagon service.

Much later, when I became secretary of defense under President Obama, a priority of mine was to make sure that the bridges between the Pentagon and the tech community were strong. I believed that I needed to be not only the secretary of defense for today—defeating ISIS and deterring war with Russia, China, North Korea, and Iran—but also the secretary of defense for tomorrow, making sure new technology was available for whatever unforeseen dangers might emerge.

With that goal in mind, I helped create an expanding network of Pentagon outposts called Defense Innovation Units Experimental (DIUx)—in tech hubs like Silicon Valley, Boston, and Austin, Texas—where technologists and new companies can learn about defense issues. They are also places to learn about funding—the Pentagon spends $72 billion per year on research and development, more than twice the total for Google, Apple, and Microsoft combined. And it works both ways: at DIUx, the Pentagon's sluggish bureaucracy can learn the ways of the startup culture.

While in Washington, I also created the Defense Digital Service to bring technologists into the Pentagon and give them a chance to do a "tour of duty" for a few months or a year to solve critical problems like planning air strikes precisely to avoid harming civilians, or protecting defense networks from hacking. People who joined often told me their work there was the most meaningful of their early careers and changed their outlook when they returned to the private sector.

I wanted even more ideas for linking the tech community to defense. So I set up a Defense Innovation Board that was chaired by Alphabet's executive chairman, Eric Schmidt, and included leading tech thinkers like Amazon's Jeff Bezos and LinkedIn's Reid Hoffman. I wanted

ANDY FRIEDMAN

Ash Carter

to make sure that the best innovative thinking was available to defense.

Defense is far from the only area where the public interest sorely needs the input of technical people. The Internet and social media have radically transformed commerce and community, but they've also created new opportunities for hostility, lies, and isolation. Now a variety of actors—including government—are urging digital companies like Facebook to address those challenges. It's in their best interest to do so, because if the technologists themselves don't do it, the problems will instead be "solved" by lawyers, legislators, and regulators.

There's also technology's effect on jobs. Driverless cars will make roads safer and give hours of time back to commuters. They'll also eliminate the jobs of millions of people who make their living driving trucks, cabs, and delivery vehicles. Perhaps technology can help by creating new types of jobs. Keeping the American dream real, so that people have a chance to improve their lives, is essential to a cohesive society—as today's politics sometimes show.

Meanwhile, as some old jobs go away, many companies report having trouble finding qualified employees for new jobs. Here again, technology can help—by making technical training more widespread, making it available at various levels, and making it lifelong, via online delivery.

Remembering the lessons the atomic physics generation taught me when I was starting out gives me hope about the role technologists can play in handling the bright opportunities—and civic dilemmas—that innovation brings. So too does my experience as secretary of defense.

Young technologists I have met want to make a difference. They know that the progress of science cannot be stopped, but it can also be shaped for good. They know that if they don't join the effort, choices will be made by politicians or judges who might not have much technical background or insight. Worse, the effects of change might fall victim to forces of backwardness and darkness. Many of these people don't necessarily want jobs in government or philanthropy, at least not for an entire career. They want to join the most powerful engine of making a difference: private companies fueled by technology. But they also want to be sure they invent solutions to problems that technology creates, just like the atomic bomb scientists who invented arms control in a distant era.

Ash Carter was secretary of defense from 2015 to 2017. He is an Innovation Fellow at MIT and director of the Harvard Kennedy School's Belfer Center for Science and International Affairs.

Big challenges are solvable.

The Solve community is a carefully curated group of member organizations that value innovation and create positive social and environmental impact.

Solve members:

- Obtain exclusive access to innovators and innovative ideas
- Join a network of cross-sector thought leaders and change makers
- Gain entry to the exclusive **Solve at MIT** conference in May 2018
- Offer input on new Solve challenges
- Receive personalized support from Solve staff

Realize your company's social and environmental goals and create value for your business, stakeholders, and society.

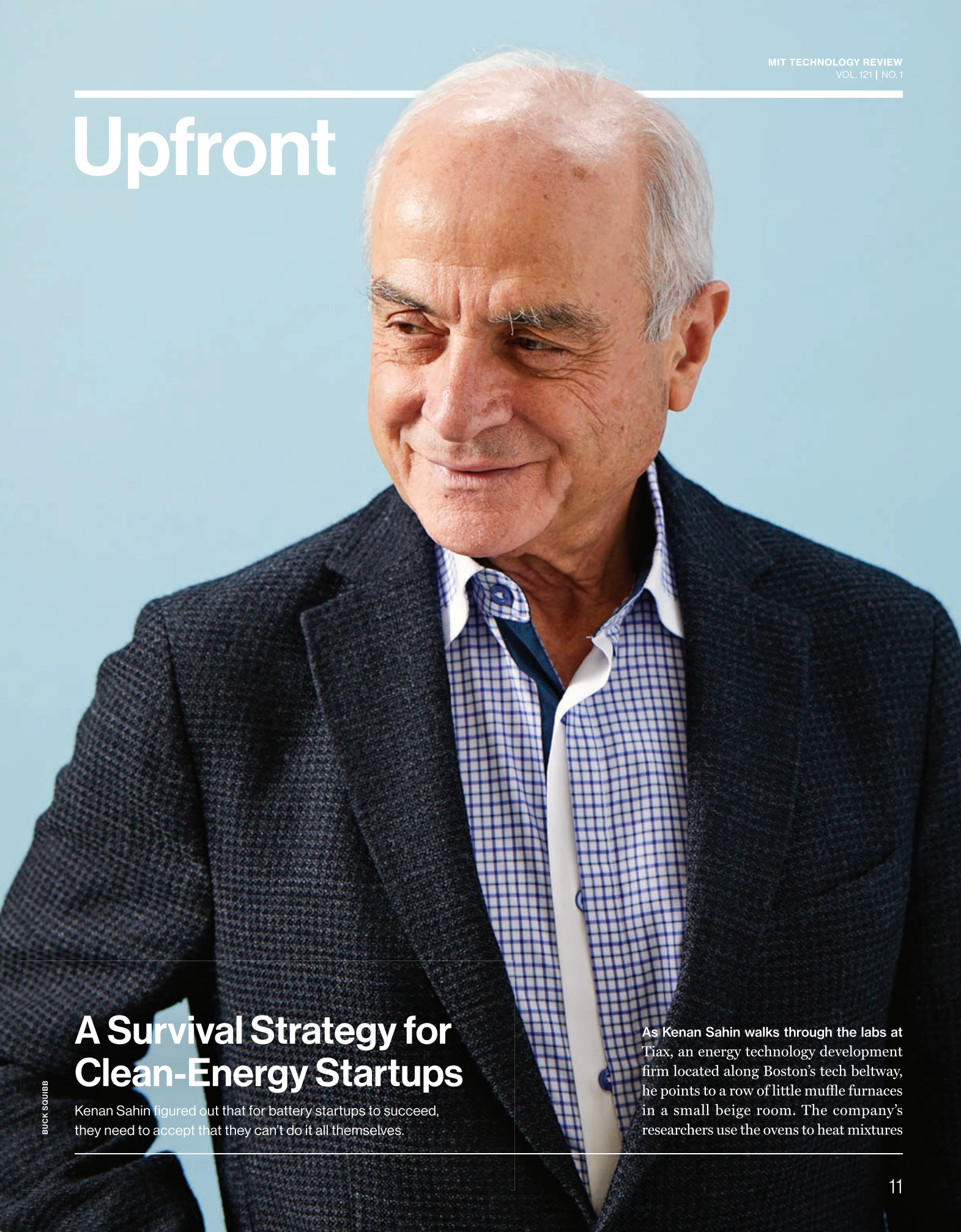
Learn more:
solve.mit.edu/join

For membership inquiries:
membership@solve.mit.edu

SOLVE

Massachusetts Institute of Technology

Upfront



BUCK SQUIBB

A Survival Strategy for Clean-Energy Startups

Kenan Sahin figured out that for battery startups to succeed, they need to accept that they can't do it all themselves.

As Kenan Sahin walks through the labs at Tiax, an energy technology development firm located along Boston's tech beltway, he points to a row of little muffle furnaces in a small beige room. The company's researchers use the ovens to heat mixtures

Upfront

of metals, producing slight variations of a nickel-rich cathode recipe that Sahin believes will improve the energy density, cycle life, and price of lithium-ion batteries. If he's right, it would represent a rare genuine advance in battery materials, one that could help tip electric vehicles into the consumer mainstream. It's the result of 15 years of research and tens of millions of dollars of personal investment, reflecting Sahin's patient and deliberate approach to the innovation process.

Sahin, 75, is best known for selling his billing software company, Kenan Systems, for $1.5 billion to Lucent in 1999, without having taken a dollar of outside investment. Since then, he has spent much of his time and fortune quietly working to push battery technologies forward, launching Tiax in 2002 to produce and foster promising advances before turning them over to a marketplace that's brutalized green-tech startups.

The company has been developing cathode materials from the start, and this spring it announced that a spinout, CAMX Power, was emerging from stealth mode. Sahin himself has become a cathode evangelist, arguing that improving the battery electrodes that power electric vehicles is the fastest way to transform the transportation sector, promising to cut costs and boost mileage range. "Cathode materials are the key to the electrification of vehicles," says Sahin, in a slight Turkish accent that's lingered since he first arrived in the United States on an exchange program at the age of 16.

A deep innovation crisis in the U.S. is smothering clean-energy startups.

But at least as notable as any technology advance is the company's market survival strategy. Instead of making the cathode powder itself, CAMX lined up deals with two of the world's largest chemical manufacturers, U.K.-based Johnson Matthey and Germany's BASF, to produce and sell the material to battery makers. It's a tactic designed to avoid the kind of capital expenditures that have doomed many battery wannabes, while allowing the startup to focus on pushing cathode technologies further still.

But making any inroads in the battery industry is a huge challenge, even when a startup has achieved a technological advance. Getting new materials or components to the marketplace requires shifts in practices and significant up-front investments on the part of suppliers, manufacturers, and end customers. The real test for CAMX will be whether battery makers, auto manufacturers, and electronics companies ultimately see enough promise to put the novel materials to work.

Coin cells and other components of CAMX's battery kit.

Innovation backlog

After earning his PhD in 1969 at MIT's Sloan School of Management, Sahin spent years in academia. But in 1982, he decided to commercialize some of his research in expert systems and data processing, launching Kenan Systems with a $1,000 personal investment.

The company ultimately built transaction systems for major companies in telecommunications and banking, catching the eye of Lucent Technologies, the telecom equipment giant. Sahin spent the next several years as vice president of software technology at Lucent's famed Bell Labs research division. Around this period, he came to believe there was a fundamental breakdown between academic research and private industry, creating what he has called an "innovation backlog" as corporations dismantled R&D labs and venture capitalists grew more risk averse.

Three years after the sale, he established Tiax to provide additional support for promising early ideas, jump-starting the company by acquiring the technology

division of the once-prominent consulting firm Arthur D. Little for $16.5 million. "It bothers me that so many wonderful inventions are stagnating," he told the *New York Times* after the purchase.

And it's only gotten worse since then, he says now.

Sahin has come to believe that a deep innovation crisis in the United States is smothering clean-energy startups in their infancy. The short, cheap path to disruption that works for online businesses routinely fails in energy, where new companies face years of development, high manufacturing costs, and deeply entrenched players.

He argues that startups in the sector should focus on what startups do best—innovating—while finding ways to partner with established companies to transform advances into products. That strategy could offer better odds of long-term survival for any given firm, he says.

At CAMX, Sahin is hoping to put this theory into action. The appeal of using a greater proportion of nickel in lithium-ion battery cathodes is the metal's high energy density. That means it can store and release a lot of the lithium ions that ultimately power gadgets and cars, delivering energy over long periods between charges. Using more nickel also makes it possible to use significantly less cobalt, which is rare and expensive.

But most work on high-nickel cathodes to date, including research on the same basic mix of lithium, nickel, and oxide that CAMX is using, has consistently run into stability problems that shorten a battery's life. That's an obvious drawback in vehicles, since no one wants to buy a $35,000 car that only lasts three years.

CAMX, however, has developed and patented a molecularly engineered composition that stabilizes the materials by placing small amounts of cobalt in crucial areas. This advance amounts to a new class of lithium-ion cathodes that could enable cheaper electric vehicles with longer range, according to Sahin.

A researcher at work in CAMX Power's cell-fabrication facility.

BUCK SQUIBB

In an investor presentation last fall, Johnson Matthey said the CAMX materials delivered as much as a 25 percent improvement in energy density over the nickel-manganese-cobalt cathode materials used in many electric vehicles today, and about a 5 percent gain over an advanced chemistry going into upcoming models. The company announced that it will invest around $260 million to begin building the first plant to produce the materials in 2018.

Think like Facebook

Despite the obvious need for better energy storage and the excitement around new approaches, the marketplace has been brutal for startups in this sector so far. The high cost of manufacturing, the

Upfront

strength of incumbent players, technical challenges, and the slow pace of adoption for new technologies has forced a series of onetime darlings to pivot, retrench, or file for bankruptcy, including A123 Systems, Alevo, Ambri, Aquion Energy, EnerVault, and LightSail Energy. In the process, venture capital interest has cooled as investors returned their focus to safer, more predictable, shorter-term bets on software, social-media, and online businesses.

Observing the stumbles of battery ventures and other green-tech firms, Sahin came to believe that makers of energy materials needed to learn from these fast-growing Internet businesses. "Google, Facebook, Airbnb—these are all piggyback companies that sit on the Internet," he says. "They did not build the Internet."

"But in the materials domain, the standard thinking is, 'If we invent it, we're going to make it,'" he adds. "I said, 'No, no, no. We will find a manufacturing partner, but we have to make it makeable.'"

That presented a challenge: an unknown startup had to convince battery giants or their materials suppliers that it had built a better technology. His initial entreaties to companies including Panasonic, the world's leading automotive battery supplier, were rebuffed. The battery makers were unwilling to spend the time and money to evaluate some other company's materials. When Sahin finally did persuade one to try, by leveraging a career's worth of connections, the company's engineers didn't know how to—or didn't care to—test them properly.

Ultimately, CAMX had to take two big, expensive steps to move forward: it built a $10 million pilot factory in Rowley, Massachusetts, to prove that the material could be produced at scale, and it developed a "battery kit" that any partner could use to create small cells that would demonstrate the performance of CAMX's materials.

During an interview in Sahin's second-floor office, filled with plaques and plates recognizing his achievements in academia, business, and philanthropy, he places a cardboard box on a round table in the middle of the room. He's wearing blue jeans and leather moccasins, paired with a well-cut sports jacket and a dress shirt with detailed blue stitching down the placket.

Sahin opens the box and starts pulling the contents from their black foam compartments: bottles of electrolyte and binders, the company's own cathode powder, and assembly instructions in assorted languages.

It was only by creating such a kit, he explains, that the company was able to demonstrate the advantages of its cathode material. This allowed potential partners to test and compare the materials without any financial investment, and only a little of their own time. Ultimately, the improvements were significant enough to convince Johnson Matthey and BASF to strike manufacturing deals, while allowing CAMX to retain its intellectual property and pursue additional deals with others. (Sahin has argued strongly that startups need to resist pressure to give away their IP as part of early revenue or funding deals.)

"You need to be a lot better ... If you're 10 percent better, no one will talk to you."

"It required $75 million in private capital and 15 years and everything I learned in academia, at Bell Labs, you name it—and we just managed it," Sahin says. "And there are dozens, hundreds, of small companies out there that want to get there too."

That's the driving motivation for what Sahin describes as the "next stage" in his vision for the company: a new division that offers consulting and evaluation services to startups working on battery components, including cell separators, silicon anodes, or even competing cathode materials. The division will also prepare customized battery kits that these firms can use to help potential partners validate their technologies.

"So what took us 10 years can take them 10 months," he says.

But of course, it remains to be seen whether CAMX itself will succeed. In fact, it's likely to take years before the company's invention lands in any consumer product. Both battery makers and auto manufacturers will need to thoroughly and independently evaluate the materials, as neither can afford to push out a product that may not perform well or safely in the real world over time.

The odds of success for any battery material or component startup are very low, even when the firm is well funded. The company has to demonstrate an advance that's substantial, scalable, and largely free of trade-offs in order to persuade players further along the supply chain to make massive up-front investments in time and resources.

"You need to be a lot better than the incumbent," says Gerbrand Ceder, a professor of materials science at the University of California, Berkeley, who oversees a research group co-located at Lawrence Berkeley National Laboratory that's exploring promising battery materials. "If you're 10 percent better, no one will talk to you."

For his part, Sahin is confident in the capabilities of CAMX's materials. Given the projected electric-car sales in the coming years, he believes there will be plenty of business to go around. "A $2 trillion disruptive industry is going to happen," he says. "It is happening. And it's right under our nose." —*James Temple*

Andrew Ng Has a Chatbot That Can Help with Depression

Woebot combines cognitive behavioral therapy with advances in natural language to create a virtual counselor.

I'm a little embarrassed to admit this, but I've been seeing a virtual therapist.

It's called Woebot, and it's a Facebook chatbot developed by Stanford University researchers that offers interactive cognitive behavioral therapy. Andrew Ng, a prominent figure who led efforts to develop and apply the latest AI technologies at Google and Baidu, is now lending his backing to the project by joining the board of directors of the company offering Woebot's services.

"If you look at the societal need, as well as the ability of AI to help, I think that digital mental-health care checks all the boxes," Ng says. "If we can take a little bit of the insight and empathy [of a real therapist] and deliver that, at scale, in a chatbot, we could help millions of people."

For a few days I tried out its advice for managing thought processes and for dealing with depression and anxiety. While I don't think I'm depressed, I found the experience positive—impressive given how annoying I find most chatbots to be.

"Younger people are the worst served by our current systems," says Alison Darcy, a clinical research psychologist who came up with the idea for Woebot while teaching at Stanford in July 2016. "It's also very stigmatized and expensive."

Depression is certainly a big problem. It is now the leading form of disability in the U.S., and 50 percent of U.S. college students report suffering from anxiety or depression. Darcy and colleagues tried several different prototypes on college volunteers, and they found the chatbot approach to be most effective. In a study they published in 2017 in a peer-reviewed medical journal, Woebot was found to reduce the symptoms of depression in students over the course of two weeks.

In my own testing, I found Woebot to be surprisingly good at what it does. A chatbot might seem like a crude way to deliver therapy, especially given how clumsy many virtual helpers often are. But Woebot works smoothly thanks to some pretty impressive natural-language technology. The program states up front that no person will see your answers, but it also offers ways of reaching someone if your situation is serious. I mostly used predefined answers that it offered me, but even when I strayed from the script a little, it didn't get tripped up.

You are guided through conversations with Woebot, but the system is able to understand a pretty wide range of answers. It checks in with you every day and directs you through the steps. For example, when I tried telling Woebot I was stressed about work, the bot offered ways of reframing my feelings to make them seem more positive.

The emergence of a real AI therapist is, in a sense, pretty ironic. The very first chatbot, Eliza, developed at MIT in 1966 by Joseph Weizenbaum, was designed to mimic a "Rogerian psychologist." Eliza used a few clever tricks to create the illusion of an intelligent conversation—for example, repeating answers back to a person or offering open-ended questions such as "In what way?" and "Can you think of a specific example?" Weizenbaum was amazed to find that people seemed to believe they were talking to a real therapist, and that some offered up very personal secrets.

Darcy also says both Eliza and Woebot are effective because conversation is a natural way to receive emotional support. She adds that people seem happy to suspend their disbelief, and seem to enjoy talking to Woebot as if it were a real therapist. "People talk about their problems for a reason," she says. "Therapy is conversational." —*Will Knight*

TO MARKET

Guardian GT

Robot for heavy labor

COMPANY:
Sarcos Robotics

PRICE:
N/A

AVAILABILITY:
Now

SARCOS ROBOTICS

Say hello to Guardian GT, which wants to take the strain out of your manual labor. This mean-looking machine from Sarcos Robotics is designed to give you superhuman strength. Its pair of seven-foot arms, each able to lift 500 pounds, is controlled with eerie smoothness by a human. The controller provides force feedback so that the operator can feel what's happening—though it takes only five pounds of force, instead of the full 1,000. The arms are scaled like those of a human in a bid to make the system intuitively easy to use. Sarcos says it's designed to perform tasks like emptying massive disposal bins or moving huge metal pipes. —*Jamie Condliffe*

Upfront

Will You Be Among the First to Pick Your Kids' Genes?

As machine learning unlocks predictions from DNA databases, scientists say parents could have choices never before possible.

Nathan Treff was diagnosed with type 1 diabetes at 24. It's a disease that runs in families, but it has complex causes. More than one gene is involved. And the environment plays a role too.

So you don't know who will get it. Treff's grandfather had it, and lost a leg. But Treff's three young kids are fine, so far. He's crossing his fingers they won't develop it later.

Now Treff, an in vitro fertilization specialist, is working on a radical way to change the odds. Using a combination of computer models and DNA tests, the startup company he's working with, Genomic Prediction, thinks it has a way of predicting which IVF embryos in a laboratory dish would be most likely to develop type 1 diabetes or other complex diseases. Armed with such statistical scorecards, doctors and parents could huddle and choose to avoid embryos with failing grades.

IVF clinics already test the DNA of embryos to spot rare diseases, like cystic fibrosis, caused by defects in a single gene. But these "preimplantation" tests are poised for a big leap forward as it becomes possible to look more deeply at an embryo's genome and create broad statistical forecasts about the person it would become.

The advance is occurring, say scientists, thanks to a growing flood of genetic data collected from large population studies. As statistical models known as predictors gobble up information about the DNA and health of hundreds of thousands of people, they're getting more accurate at spotting the genetic patterns that foreshadow disease risk. But they have a controversial side, since the same techniques can be used to project the eventual height, weight, skin tone, and even intelligence of an IVF embryo.

In addition to Treff, who is the company's chief scientific officer, the founders of Genomic Prediction are Stephen Hsu, a physicist who is vice president for research at Michigan State University, and Laurent Tellier, a Danish bioinformatician who is CEO. Both Hsu and Tellier have been closely involved with a project in China that aims to sequence the genomes of mathematical geniuses, hoping to shed light on the genetic basis of IQ.

Spotting outliers

The company's plans rely on a tidal wave of new knowledge showing how small genetic differences can add up to make one person, but not another, likely to end up with diabetes, a neurotic personality, or a taller or shorter height. Already, such "polygenic risk scores" are used in direct-to-consumer gene tests, such as reports from 23andMe that tell customers their genetic chance of being overweight.

For adults, risk scores are little more than a novelty. But if the same information is generated about an embryo, it could have existential consequences: who will be born, and who stays in a laboratory freezer?

"I remind my partners, 'You know, if my parents had this test, I wouldn't be here,'" says Treff, a prize-winning expert on diagnostic technology who is the author of more than 90 scientific papers.

Genomic Prediction was founded this year and has raised funds from venture capitalists in Silicon Valley, though it declines to say who they are. Tellier says the company plans to offer reports to IVF doctors and parents identifying "outliers"—those embryos whose genetic scores put them at the wrong end of a statisti-

TIM LAHAN

cal curve for disorders such as diabetes, late-life osteoporosis, schizophrenia, and dwarfism, depending on whether models for those problems prove accurate.

The company's concept, which it calls expanded preimplantation genetic testing, or ePGT, would effectively add a range of common disease risks to the menu of rare ones already available, which it also plans to test for. Its promotional material uses a picture of a mostly submerged iceberg to get the idea across. "We believe it will become a standard part of the IVF process," says Tellier, just as a test for Down syndrome is a standard part of pregnancy.

Some experts say it's premature to introduce polygenic scoring technology into IVF clinics—though perhaps not by very much. Matthew Rabinowitz, CEO of the California-based prenatal-testing company Natera, says he thinks predictions obtained today could be "largely misleading" because DNA models don't function well enough. But Rabinowitz agrees that the technology is coming along.

"You are not going to stop the modeling in genetics, and you are not going to stop people from accessing it," he says. "It's going to get better and better."

Sharp questions

Testing embryos for disease risks, including risks for diseases that develop only late in life, is considered ethically acceptable by U.S. fertility doctors. But the new DNA scoring models mean parents might be able to choose their kids on the basis of traits like IQ or adult weight. That's because, just like type 1 diabetes, these traits are the result of complex genetic influences the predictor algorithms are designed to find.

"It's the camel's nose under the tent. Because if you are doing it for something more serious, then it's trivially easy to look for anything else," says Michelle Meyer, a bioethicist at the Geisinger Health System who analyzes issues in reproductive genetics. "Here is the genomic dossier on each embryo. And you flip through the book." Imagine picking the embryo most likely to get into Harvard like Mom, or to be tall like Dad.

For Genomic Prediction, a tiny startup based at a tech incubator in New Jersey, such questions will be especially sharply drawn. That is because of Hsu's longstanding interest in genetic selection for superior intelligence. In 2014, Hsu authored an essay titled "Super-Intelligent Humans Are Coming," in which he argued that selecting embryos for intelligence could boost the resulting child's IQ by 15 points.

Genomic Prediction says it will only report diseases—that is, identify those embryos it thinks would develop into people with serious medical problems. Even so, on his blog and in public statements, Hsu has for years been developing a vision that goes far beyond that.

"Suppose I could tell you embryo four is going to be the tallest, embryo three is going to be the smartest, embryo two is going to be very antisocial. Suppose that level of granularity was available in the reports," he told the conservative radio personality Stefan Molyneux this spring. "That is the near-term future that we as a civilization face. This is going to be here."

Measuring height

The fuel for the predictive models is a deluge of new data, most recently genetic readouts and medical records for 500,000 middle-aged Britons that were released in July by the UK Biobank, a national precision-medicine project.

The data trove included, for each volunteer, a map of about 800,000 single-nucleotide polymorphisms, or SNPs—points where their DNA differs slightly from another person's. The release caused a pell-mell rush by geneticists to

QUOTED

"This would completely change her world."

—Brett Kopelan, executive director of the Dystrophic Epidermolysis Bullosa Research Association of America, on the potential of gene therapy to help his 10-year-old daughter and others with devastating skin disorders.

"To believe we can solve the greatest of all problems in the next few weeks or months is a bit too ambitious."

—Tomaso Poggio, a professor at the McGovern Institute for Brain Research, on the hype surrounding artificial intelligence.

"We should be getting ready for bigger fire years."

—Park Williams, a bioclimatologist at Columbia University, on the effect of climate change on wildfires.

BY THE NUMBERS

18

Number of countries where social media was used to influence elections in 2017, according to the democracy advocacy group Freedom Now.

26

Number of operations a man named Brian Madeux has undergone for complications related to Hunter syndrome. In November Madeux became the first person to officially have gene editing take place inside his body, via a treatment from Sangamo Therapeutics.

65%

Proportion of jobs created since 2010 that require at least moderate digital skills, according to a November report from the Brookings Institution.

202

Number of the world's 500 fastest supercomputers that are currently located in China. The U.S., in comparison, has 144 of them.

Upfront

update their calculations about exactly how much of human disease, or even routine behaviors like bread consumption, these genetic differences could explain.

Armed with the U.K. data, Hsu and Tellier claimed a breakthrough. For one easily measured trait, height, they used machine-learning techniques to create a predictor. They reported that their model could, for the most part, predict people's height from their DNA data to within three or four centimeters.

Tellier says Genomic Prediction will zero in on disease traits for which the predictors already perform fairly well, or will soon. Those include autoimmune disorders like the illness Treff suffers from. In those conditions, a smaller set of genes dominates the predictions, sometimes making them more reliable.

The company doesn't intend to give out raw trait scores to parents, only to flag embryos likely to be abnormal. That is because the product has to be "ethically defensible," says Hsu: "We would only reveal the negative outlier state. We don't report, 'This guy is going to be in the NBA.'"

But by now, polygenic scores have become a routine aspect of DNA tests. A company called HumanCode sells a $199 test that uses SNP scores to tell people how tall their kids might be. In the dairy cattle industry, polygenic tests are used to rate animals for how much milk they'll produce.

Some scientists doubt the scores will prove useful at picking better people from IVF dishes. Even if they're accurate on the average, for individuals there's no guarantee of pinpoint precision. What's more, environment has as big an impact on most traits as genes do. "There is a high probability that you will get it wrong—that would be my concern," says Manuel Rivas, a professor at Stanford University who studies the genetics of Crohn's disease.

"There will be some future debate over whether this should be legal."

"If someone is using that information to make decisions about embryos, I don't know what to make of it." Efforts to introduce this type of statistical scoring into reproduction have drawn criticism in the past. In 2013, 23andMe provoked outrage when it won a patent on the idea of drop-down menus parents could use to pick sperm or egg donors—say, to try to get a specific eye color. The company, funded by Google, quickly backpedaled.

Smarter kids

Genomic Prediction recently staffed a booth at the annual meeting of the American Society for Reproductive Medicine. That organization, which represents fertility doctors and scientists, has previously said it thinks testing embryos for late-life conditions, like Alzheimer's, would be "ethically justified." It cited, among other reasons, the "reproductive liberty" of parents. It has been more ambivalent about choosing the sex of embryos, leaving that to the discretion of doctors.

Hsu thinks intelligence is "the most interesting phenotype," or trait, of all. But when he tried his predictor to see what it could say about how far along in school the 500,000 subjects from the UK Biobank had gotten (years of schooling is a proxy for IQ), he found that DNA couldn't predict it nearly as well as it could predict height.

Hsu anticipates that "billionaires and Silicon Valley types" will be the early adopters of embryo selection technology, becoming among the first "to do IVF even though they don't need IVF." As they start producing fewer unhealthy children, and more exceptional ones, the rest of society could follow suit.

"I fully predict it will be possible," he says of selecting embryos with higher IQ scores. "But we've said that we as a company are not going to do it. It's a difficult issue, like nuclear weapons or gene editing. There will be some future debate over whether this should be legal, or made illegal. Countries will have referendums on it." *—Antonio Regalado*

TO MARKET

Amazon Key

In-house delivery

COMPANY:
Amazon

PRICE:
$250

AVAILABILITY:
Now

AMAZON

The new Amazon Key service will allow the company's delivery workers to leave packages in your home even when you're not there. Question is: do you want them to? The scheme makes use of a smart lock on your door, an app, and another new Amazon product called Cloud Cam. For $250, Prime members in 37 American cities can have Amazon install the kit in their homes. When you're out, delivery drivers can let themselves in. Amazon uses an encrypted authentication process to verify that the correct driver is at the right address at the intended time. However, researchers have already demonstrated that the CloudCam can be hacked—so apparently there are some kinks to work out. *—Jamie Condliffe*

Have You Developed Ground Breaking Technology, Made a Major Discovery, or Invented a New Device?

Protect your brainstorm with the brain trust of **Allen, Dyer, Doppelt, Milbrath & Gilchrist,** a Florida-based Intellectual Property law firm established in 1972. **ADDM&G** has protected the intrinsic rights of clients' original ideas and unique technologies through the application of patents, trademarks, copyrights, licensing, infringement, trade secrets and unfair competition protection, business litigation and counseling for 44 years. **ADDM&G** serves its clients' needs locally, statewide, across the nation and around the world. *Contact **ADDM&G** today for further information.*

A D D M & G

ALLEN, DYER, DOPPELT, MILBRATH & GILCHRIST

INTELLECTUAL PROPERTY ATTORNEYS

Orlando · 407.841.2330 | Jacksonville · 904.398.7000* | Miami · 305.374.8303
Tampa · 813.639.4222* | Winter Springs · 407.796.5064 | www.addmg.com

· Copyrights · Patents · Trademarks · Litigation ·

*Satellite Office

Upfront

Why People Get Religious about Bitcoin

The cryptocurrency's price is soaring, but the fervor is about more than just an investment opportunity.

The Bitcoin phenomenon isn't about a bunch of people who all believe the cryptocurrency is a good investment. That's part of it. But for many, the belief in Bitcoin's power to transform society runs much deeper: it's almost an article of faith. Where does this fervor come from? To understand, it's important to keep in mind that "the blockchain" is not really a thing.

A blockchain is a shared, permanent, encrypted data set, created by a network of computers according to a set of software rules. But there are different ways to set up those rules. The word "blockchain" is like the word "vehicle," explains Peter Van Valkenburgh, director of research at Coin Center, a blockchain-focused think tank. Saying you are putting something on "the blockchain" is like saying you are going to use "the vehicle" to travel overseas. It makes more sense to talk about "cars, trains, boats, or rocket ships, depending on what it is about the vehicles that we are interested in," Van Valkenburgh argues.

Bitcoin is the type of vehicle that gets the most attention, and deservedly so. Its blockchain was the first, it's been running the longest, and its network is the biggest. To many people, Bitcoin's breakthrough is just as much about social innovation as it is technical. They believe the new model it represents can revolutionize how people share value and do business online.

There's a good reason for that. Bitcoin has shown that it is possible to use a network of computers, connected via the Internet, to build and maintain a set of valuable shared data—in this case a ledger of account balances that prevents counterfeiting—without the need for a trusted authority. Think about that: from a bunch of anonymous computers that have no reason to trust one another, an ironclad network has emerged that can support a whole currency. Literal money—what could be a more valuable target for hacking or compromise? And yet there it stands, unperturbed amid the chaos of the Internet.

It's heady stuff. And little wonder, then, that people think the incorruptible math underlying Bitcoin's blockchain could, if adapted properly, make business processes in a range of industries vastly more efficient.

Still, Bitcoin faces big questions over how it should modify its software to adapt to its growing popularity. Keeping the system running uses vast amounts of energy. And its blockchain is public, meaning transactions can be traced.

Bitcoin's younger cousin Ethereum generally shares these characteristics. Meanwhile, some industries that stand to benefit most from blockchains—finance and health care, for example—are also highly regulated with respect to data privacy and security. Some say the best course is to pursue different kinds of vehicles, like blockchains that have been modified so they require permission to access.

To Bitcoin acolytes, though, that misses the point. Bitcoin's scaling issues, its energy consumption, and even its privacy challenges can be addressed through research and development, they argue. They say "permissionless" blockchains like Bitcoin and Ethereum, whose networks are open to anyone who wants to use and build on them, can form a new kind of Web in which we won't have to trust banks, corporations, or governments with our valuable data.

In other words, as MIT blockchain researcher Michael Casey recently argued in a column for CoinDesk, open blockchains could "save us from the Internet's original sin." —*Mike Orcutt*

NICK LITTLE

Pursue Breakthroughs, Not Bugs

Reduce Software Delivery Cycle Time from Months to Minutes.

Manual software development processes are a drag on business. They make release days nerve-wracking. Hamper quality. Leave little time for innovation. And stress out your engineers, making it harder to retain and attract top talent.

Integnology helps you make software development exhilarating instead of exasperating. We implement Agile development, DevOps, and Continuous Integration and Delivery (CICD) solutions that are tailored to your organization. Fast, efficient and repeatable processes give your developers more time to innovate.
High quality software and constant improvements keep your customers coming back.

For a quick assessment of what fully automated software delivery can do for your business, call us at **408.806.9133** or write us at **agile@integnology.com**

INTEGNOLOGY
Enabling Business Transformation

Upfront

LEONARD GRECO

I Tried the Desktop of the Future—I'll Stick with the Past

Augmented reality may eventually help you work. But a few days with the Meta 2 headset suggest it has a way to go.

For a few days recently I augmented my reality at work, adding virtual displays to my office so that, while wearing a special headset, I could do things like type e-mails and read news and tweets without taking up real estate on my small laptop.

I did this with the Meta 2 headset, a $1,495 device from Meta, a Silicon Valley startup that is one of a handful of companies trying to bring augmented reality to the mass market. The Meta 2, which is intended for developers, needs to be connected to a beefy computer in order to work, but it's about half the price of Microsoft's HoloLens device (also still aimed just at developers), has a larger field of view, and also produces very good-looking 3-D images in real environments.

Since I'm curious about how augmented reality could be used for a regular computer-heavy work day, I concentrated on Meta's Workspace demo app. I imagined using hand gestures to open lots of Web browser windows and placing them all around me, letting YouTube videos play in the background, pulling up a giant Twitter feed, and writing e-mails, all in AR.

But the app would freeze. Many times, after a few minutes of use, an object that I was interacting with in Workspace would suddenly stick in front of my face, moving around with me no matter how I turned my head. When it did work, the images looked good. Workspace uses a bookcase-like visualization for its application launcher. It's very cool to open a browser window, start watching a video, pause it, and then turn your head to concentrate on something else; after all, you can always turn back to it later.

Meta has a lot of good ideas about how we should interact with virtual elements. Hand gestures aren't hard to figure out—to grab, say, a virtual Batman figure and move it, you hold your open hand in front of it, and when you see a closed circle appear on the back of your hand you make a fist, move the object where you want, and then open your fist.

At the risk of sounding like a wimp, I found these interactions tiring. For the most part, it's easier to just use a wireless mouse and keyboard to click things.

I also found that the headset, which weighs a bit over a pound, was too heavy for me to wear for more than 25 minutes or so at a time without getting a headache.

It sounds cool to add digital elements to the real world, right? It's something I've been writing about, testing, and looking forward to for years now. Sadly, while I wish I could tell you that the desktop of the future is just around the corner, it's at least several blocks away, if not farther.

—Rachel Metz

CRISPR 2.0 Is Here, and It's Way More Precise

It could one day be used to treat a range of inherited diseases.

You've probably heard of the molecular scalpel CRISPR-Cas9, which can edit or delete whole genes. Now, scientists have developed a more precise version of the DNA-editing tool that can repair smaller segments of a person's genome.

In two studies published in October, one in *Nature* and another in *Science*, researchers from the Broad Institute of MIT and Harvard describe a new way to edit DNA and RNA, called base editing. The approach could one day treat a range of inherited diseases, some of which currently have no treatment options.

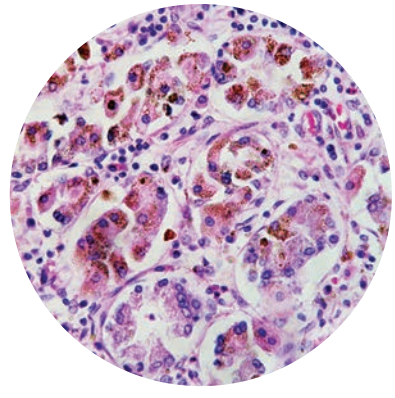
The human genome contains six billion DNA letters, or chemical bases known as A, C, G, and T. These letters pair off—A with T, and C with G—to form DNA's double helix. Base editing, which uses a modified version of CRISPR, is able to change a single one of these letters at a time without making breaks to the DNA's structure.

That's useful because sometimes just one base pair in a long strand of DNA gets swapped, deleted, or inserted—a phenomenon called a point mutation. Point mutations make up 32,000 of the 50,000 changes in the human genome known to be associated with diseases.

In the *Nature* study, researchers led by David Liu, a Harvard chemistry professor and member of the Broad Institute, were able to change an A into a G. Such a change would address about half the 32,000 known point mutations that cause disease.

To do it, they modified CRISPR so that it would target just a single base. The editing tool was able to rearrange the atoms in an A so that it instead resembled a G, tricking cells into fixing the other DNA strand to complete the switch. As a result, an A-T base pair became a G-C one. The technique essentially rewrites errors in the genetic code instead of cutting and replacing whole chunks of DNA.

"Standard genome-editing methods, including the use of CRISPR-Cas9, make double-stranded breaks in DNA, which is especially useful when the goal is to insert or delete DNA bases," Liu told journalists in October. "But when the goal is to simply fix a point mutation, base editing offers a more efficient and cleaner solution."



Liu said base editing isn't meant to replace CRISPR, but it's another option for altering the genome in an attempt to correct disease. If CRISPR is akin to a pair of scissors, base editing is more like a pencil, he said.

Previously, researchers had created base editors capable of making the opposite kind of swap—changing a G into an A. Substitutions of a G for an A in certain parts of the DNA represent about 15 percent of disease-associated point mutations. In September, Chinese researchers reported that they used one of these editing tools in an embryo to remove the genetic mutation that causes anemia.

Working in cells taken from patients, Liu and his colleagues used their base-editing tool to correct a point mutation that causes hereditary hemochromatosis, a disorder that causes the body to absorb too much iron from food. This excess iron can build up over time and cause liver cancer and other liver diseases, diabetes, heart disease, or joint disease.

Liu and his team also used the base editor in human cells to induce a mutation that suppresses sickle-cell anemia. In both studies, they detected virtually no off-target effects, or unwanted DNA insertions or deletions, which are a concern with the traditional way of using CRISPR to edit entire genes.

In the *Science* study, Feng Zhang, of the Broad Institute and MIT, used a similar base-editing method to target individual letters in RNA, DNA's chemical cousin. RNA naturally degrades in the body, so editing RNA wouldn't result in a permanent change to a person's genome.

Ross Wilson, of the Innovative Genomics Institute at the University of California, Berkeley, says base editing may eventually be a better way to treat some diseases. He says a single base pair is like a word in a paragraph of text. With conventional CRISPR technology, you would have to replace the whole paragraph.

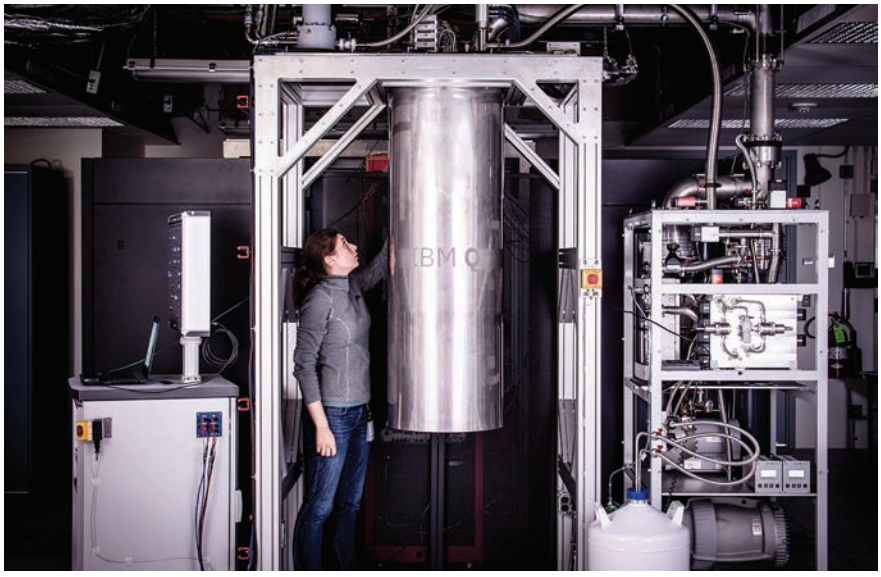
"It's a lot of DNA to move around," he says. With base editing, you could just change the single word.

Liu says he's hopeful that base editing of DNA and RNA could be used as complimentary approaches for a "broad set of potential therapeutic applications."

His lab is exploring base editing to fix blood disorders, neurological disorders, hereditary deafness, and hereditary blindness. *—Emily Mullin*

US NATIONAL LIBRARY OF MEDICINE

Upfront



New Twists in the Road to Quantum Supremacy

Quantum computers will soon surpass conventional ones, but it will take time to make the machines useful.

After decades of hype and headlines, quantum computers are finally poised to demonstrate their superiority over conventional machines. Precisely when this will happen is a bit fuzzy, though.

The point at which a quantum machine should be able to perform computations too complex to model on any conventional machine, a benchmark known as "quantum supremacy," has been believed to be about 49 qubits, the quantum equivalent of the bits that represent *1* or *0* in a conventional computer.

In October, Google's researchers appeared to be leading in the race for a 49-qubit machine. IBM subsequently surpassed this benchmark in November by announcing a quantum computer that handles 50 qubits—yet the announcement still doesn't mean quantum computing is ready for common use. IBM's system is extremely finicky and challenging to use, as are those being built by others.

Researchers at IBM's quantum research lab in Yorktown Heights, New York, have demonstrated that it's possible to model the behavior of a quantum computer beyond the 49-qubit benchmark by harnessing some clever mathematical techniques. IBM is also allowing programmers to experiment with its quantum computers through a cloud platform called IBM Q.

"We don't think there will be a single landmark or metric to gauge the capability of a quantum computer," says Bob Wisnieff, a researcher at IBM who's involved with the new simulation work. "We are actively looking at methods that show quantum machines have an advantage over classical systems."

To surpass what conventional computers can achieve by processing information in the form of conventional bits, quantum computers exploit the counterintuitive nature of physics at the atomic and subatomic scale. By harnessing superposition and entanglement—concepts that baffled and annoyed Einstein—these machines can compute in a fundamentally different way, carrying out immensely complex calculations at speeds that would otherwise be inconceivable.

Christopher Monroe, a professor at the University of Maryland who studies quantum information theory, says efforts like IBM's will prove crucial in opening up potential applications of the technology as it scales up. "I believe in the next five to 10 years we will have 100-plus-qubit machines that will be available to anyone, and this will be when useful applications will be found," Monroe says. "My guess is that useful quantum applications will only be found once we build quantum machines that can be used by people who know about difficult problems in logistics, economic markets, pattern recognition, and modeling of materials."

Interest is growing in whether quantum computers could also be useful for machine learning, although Andrew Childs, another professor at the University of Maryland, says this remains an open challenge: "I think this area is very interesting, but its promise is far from clear."

Scott Aaronson, a professor at the University of Texas at Austin and the head of its Quantum Information Center, said in a recent blog post that IBM's paper on quantum supremacy did not diminish the importance of Google's quantum supremacy goal. Aaronson also warned that the milestone will no doubt attract considerable hype. "Of course there's a risk that quantum supremacy stuff will be overhyped and misunderstood," he wrote. "In this field, what hasn't been?" *—Will Knight*

IBM

As AI Takes Over Jobs, Small Cities Will Suffer the Most

Larger cities are more resilient to technological unemployment.

It's long been clear that urbanization and automated technologies are shaping society, but it hasn't been obvious how the two forces affect each other.

Until now, perhaps. A study from MIT's Media Lab this past fall posits that the smaller the city, the more likely it is to lose jobs to automation.

Other researchers have attempted to measure the effect of technology on employment in cities, but the Media Lab authors, who have identified which jobs and skills tend to be more prevalent in smaller cities and larger ones, claim to be the first to explain why different U.S. cities are more susceptible (or resilient) to technological unemployment.

They say that bigger cities have a disproportionately large number of jobs for people who do cognitive and analytical tasks, such as software developers and financial analysts—occupations that are less likely to be disrupted by automation. Smaller cities have a disproportionate amount of routine clerical work, such as cashier and food service jobs, which are more susceptible.

The five U.S. metropolitan areas that are expected to experience the least job impact from automation are San Jose, Sunnyvale, and Santa Clara, California; Washington, D.C., and Arlington and Alexandria, Virginia; Trenton, New Jersey; Boston and Cambridge, Massachusetts; and Durham and Chapel Hill, North Carolina. All of those regions have large populations and high proportions of skilled technical and managerial occupations, particularly technology jobs. The metro areas

Metro areas deemed most at risk rely on industries such as agriculture and tourism.

deemed most at risk (among them Myrtle Beach, South Carolina; Elkhart County, Indiana; and Punta Gorda, Florida) rely on industries, such as agriculture and tourism, that have already been disrupted by technology and will probably continue to be.

"Big cities provide greater opportunities for synergies among creative, highly technical people, and that's why they attract them," explains Iyad Rahwan, an associate professor at MIT and the corresponding author of the paper. "The other dynamic is that cashiers and waiters are less idle in big cities than small cities, so large cities need fewer of them in proportion to their size."

The study is likely to draw comparisons to other recent high-profile economic analyses of automation and jobs, including a 2013 University of Oxford paper that estimated the susceptibility to "computerization" of more than 700 occupation types and forecast that 47 percent of U.S. employment was at "high risk" of automation.

The Media Lab study differs in making relative comparisons rather than absolute predictions. Though it uses the same occupation-level predictions as the Oxford paper, it offers an "expected job impact" percentage for 380 cities rather than calculating an overall technological unemployment number for the entire United States.

"For us, the question is: How can we anticipate future changes, not just related to robotics but also machine learning, algorithms, chatbots, and voice recognition, which are going to disrupt people who are in white-collar occupations as well [as in blue-collar jobs]?" says Rahwan. *—Elizabeth Woyke*

TO MARKET

Pixel Buds

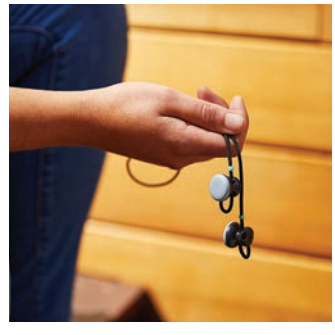
Real-time translation earbuds

COMPANY:
Google

PRICE:
$159

AVAILABILITY:
Now

GOOGLE



Google's new Pixel Buds wireless earbuds promise real-time translation via Google Translate and one of the company's Pixel smartphones. One person wears the Pixel Buds while another person holds the phone. The earbud wearer speaks English (the default) or another language, and what that person says is translated and spoken aloud by Google Translate on the phone; the smartphone holder's response is then translated and heard through the earbuds. They work as advertised, a few blips aside. One problem: the Pixel Buds are chunky and feel heavy in your ears. Making mobile, gadget-based translation work well is tricky, though, and Google does accomplish that. *—Rachel Metz*

Upfront

An Electric Semi Won't Work—but Seven in a Row Might

Platooning might make the economics reasonable for short-haul electric trucking.

Ever since Elon Musk announced his plan to roll out the electric Tesla Semi last summer, industry observers and battery experts have wondered how the company could make it work.

Researchers have long asserted that current lithium-ion batteries are too heavy and expensive for heavy-duty trucking. But a Reuters report in August raised an interesting possibility: correspondence between Tesla and regulators in the Nevada Department of Motor Vehicles suggested the company hoped to test multiple trucks driving in a platoon formation, relying on autonomous-driving technology.

Following the Reuters report, battery researchers at Carnegie Mellon University decided to take a close look at this possibility. They concluded that platooning could make heavy-duty trucks more cost competitive, at least with enough semis, according to a study published in October in *ACS Energy Letters*. The sweet spot appears to be seven vehicles driving together on trips shorter than 300 miles, which would reduce aerodynamic drag by 50 percent. Longer hauls would still face exorbitantly high costs.

Venkat Viswanathan, an assistant professor of mechanical engineering at Carnegie Mellon, did the analysis with Shashank Sripad and Matthew Guttenberg, graduate researchers in the department. In the same journal in June, Viswanathan and Sripad cast considerable doubt on the economic feasibility of a solo-operating electric semi, concluding that such a vehicle "would be limited to a driving range well under 600 miles, a small payload capacity, and a prohibitively high cost."

So how do the economics change when you string together seven electric trucks?

If they only need to travel a range of 300 miles, the required battery pack drops from 1,100 kilowatt-hours to 880 kilowatt-hours, and the cost of the pack falls from about $200,000 to $158,000, "which is quite cost competitive," Viswanathan says. As a bonus, the potential cargo payload actually increases over the average cargo weight, from 16 tons to 25.5 tons.

By way of comparison, the total cost of an average diesel-powered truck is about $120,000, and the vehicle can run for about 1,000 miles on a single fill-up.

But the economics still don't seem to work for long-haul electric trucking, even with extended platooning. A semi with 900 miles of range in such a scenario would require a 2,600-kilowatt-hour battery pack that would cost around $420,000.

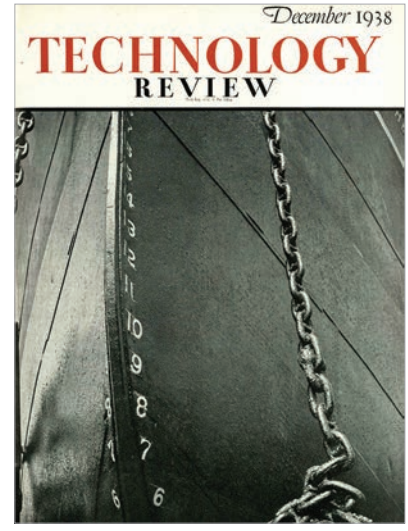
Stringing together seven trucks would represent "some advanced platooning," says Bryant Walker Smith, an assistant law professor at the University of South Carolina who focuses on autonomous driving.

That number is well beyond the two or three that most platoon developers are initially aiming for, and more than any single carrier usually has traveling together at a time, he says.

Tesla didn't reveal any prices when it finally unveiled the semi in November, but did say it would come equipped with either 300 or 500 miles of range, and include autonomous and platooning capabilities. *—James Temple*

80 YEARS AGO

An Amazing Capacity



Although there are now only about 15 cities in this country which have enough telephone traffic of a nature to justify its use under present condition, the coaxial cable—a copper tube with a concentric wire inside—has an amazing capacity for the transmission of conversations. Over a pair of such cables it is possible to transmit simultaneously 240, 360, or 480 separate conversations, the number depending upon the spacing of repeater stations. Aside from its possibilities for telephone communication, the coaxial cable holds great promise for carrying television signals.

There are—if you have a statistical tooth—over 37,000,000 telephones in service throughout the world, of which some 19,600,000 are in the United States. Of this number approximately 8,000,000 are dial instruments operating through automatic machine switchboards.

Excerpted from "The Trend of Affairs," from the December 1938 issue of Technology Review.

Get MIT Technology Review delivered to your inbox

EVERY DAY.

↓The Download
Your daily newsletter of the tech stories that matter most

THREE THINGS YOU NEED TO KNOW TODAY
The most important stories of the day

TEN FASCINATING THINGS
Provocative items from the world of technology

AND MUCH MORE

Sign up now:
technologyreview.com/inbox

MIT Technology Review

Q+A

Raffi Krikorian

Politics has become a technological arms race. In the 2008 and 2012 U.S. presidential elections, the Democrats outgunned their rivals. In 2016, the Republicans fought back, using big-data analytics and microtargeting of online ads to help propel Donald Trump into the White House. Raffi Krikorian wants to get the Democrats out ahead again. As the chief technology officer of the Democratic National Committee, the MIT graduate is reshaping his party's tech strategy. Krikorian, an expert in software engineering, previously led Uber's Advanced Technologies Center and got its first fleet of driverless cars on the road. Before that, he headed the team that managed Twitter's tech infrastructure. He spoke with *MIT Technology Review*'s San Francisco bureau chief, Martin Giles.

Why did you leave a high-profile job in Silicon Valley to take a post at the DNC?
After the presidential election, I just felt that the world was broken and I needed to find a place where I could apply what I'd learned in my previous roles to see if I could make a difference.

During the election, the DNC suffered a damaging e-mail hack. What steps have you taken to improve security?
Security's an arms race. We have a target on us in the same way that most multinational corporations do, but we don't have the budget of a big company. All our services such as e-mail have now been moved to cloud infrastructure run by companies like Microsoft and Google. We're also focusing on culture change. We actively phish our own people and publicize internally which teams have the worst compliance. We're also in the final stages of hiring a chief security officer.

What keeps you awake at night beyond security?
In electoral politics, unlike other jobs I've had, you can't move the ship dates. I'm always worried whether we'll have enough time to make the kinds of technological and cultural changes we need to make across the party. We're not just trying to catch up to where we think the Republicans are; we're attempting to do a massive leapfrog.

What progress have you made?
Campaigns are incredibly intense from the outset, and campaign managers tend to stick with what they've done before or to make a few incremental changes. We're encouraging them to experiment with more revolutionary technologies. We're creating the infrastructure to do real-time analytics and to make data science tools widely available and easy to use. And we're working on a platform strategy that allows us to easily plug in and vet new technologies for things such as canvassing and voter mobilization.

Do you see AI being used more extensively in future campaigns?
We need to be starting long-term, authentic conversations today with every American in order to get to the next presidential election in 2020. That means developing a deeper appreciation of the different issues that interest people. I think that artificial intelligence and machine learning will help us to better understand and segment audiences on a scale that's not been done before, even by some of the biggest companies in the world.

Are companies like Twitter and Facebook doing enough to tackle fake news and its influence on political campaigns?
No, I don't think my former employer or Facebook are doing enough here. It's certainly a very difficult problem. At the heart of it are things like fake accounts, hijacked accounts, and trolling accounts. We're now seeing outside researchers doing some really interesting work to try and identify the bots spreading fake news.

How can we get more transparency in online political advertising?
Part of the answer is greater clarity from social platforms. They need to make it obvious who is paying for political ads online and how much they're spending. This would fix a lot of the problem, but there needs to be some formal regulation of online political advertising too.

Digital voting systems are vulnerable to hacking. What can be done to make them more secure?
From a technology standpoint, I think it's going to be a combination of open-source software with verifiable code and paper trails. If we had a lot of academics willing to help us with verifiable code, and paper trails to show what the electronic machines actually recorded, we'd be in a much better place. I would love to see national standards that every state would need to follow when purchasing voting machines.

Given your experience at Uber, when do you think we'll all be heading to the polls in driverless cars?
Hopefully, a whole bunch of people will be using them to vote in the 2024 presidential election.

KATE WARREN

A new wave of gene-edited crops are dodging regulators, and they're about to reach stores.

THESE ARE NOT YOUR FATHER'S GMOS

by Antonio Regalado
Photographs by Matthew Hintz

When I visited Jason McHenry's farm in South Dakota, the young farmer, dressed in worn jeans and sunglasses, led me up a slippery steel ladder on the side of a grain bin. We tumbled through the manhole into a shifting mountain of soybeans. You could sift them through your fingers and taste their sweet, cloudy flavor.

The U.S. soybean crop is four billion bushels a year, about 240 billion pounds. It generates the most cash receipts for American farms after cattle and corn. Of those beans, more than 90 percent are genetically modified organisms, or GMOs—that is, they've been genetically enhanced, most often through the addition of a gene from a soil bacterium that renders them immune to the weed killer glyphosate, commonly known as Roundup.

The 4,000 bushels McHenry and I were sitting in, however, represent a new type of plant that's been modified using gene editing. A startup had employed the technology to introduce changes in two genes involved in fatty-acid synthesis, so that oil pressed from the beans is more like olive oil than typical soy oil.

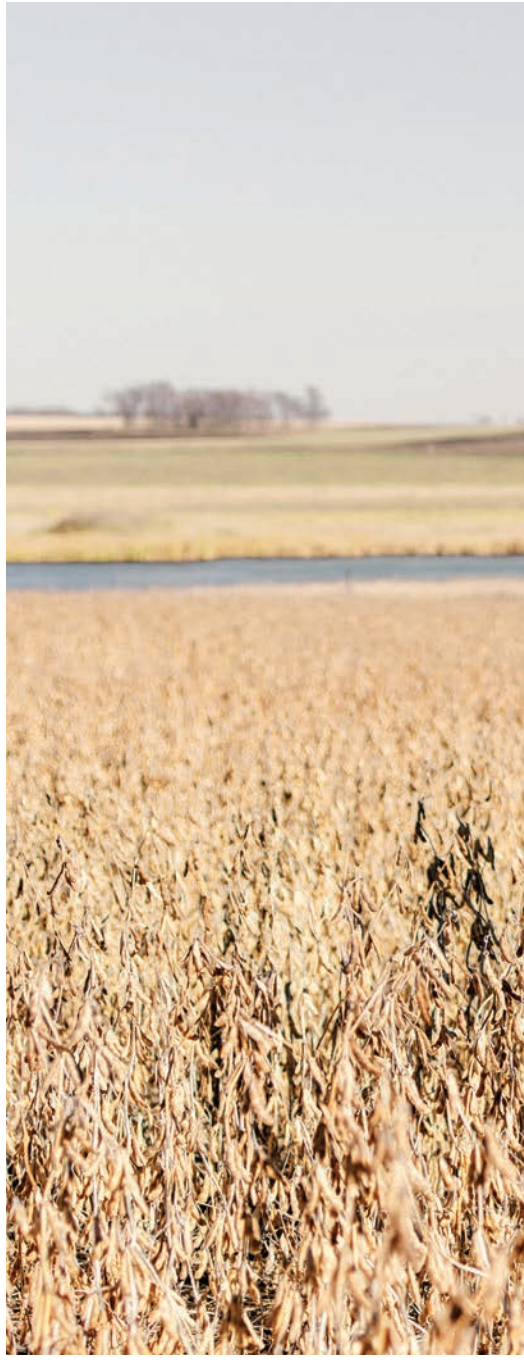
McHenry first heard the pitch for the beans last December, at a hotel near the cooperative of South Dakota soybean processors. "We have something new and exciting," a salesman told the farmers. "You've heard about the ban on trans fats?" Soybean oil has been losing market share since the U.S. government banned unhealthy fats created when soy oil is partially hydrogenated and turns to a solid (think Crisco). Those fats have been killing people. They're bad food.

Oil from the gene-edited beans could solve that problem, because it doesn't need to be processed in the same way. Any farmer who agreed to plant the beans, McHenry heard, would be part of the wave of innovation filling store shelves with Greek yogurts, green packaging, and healthy ingredients. What's more, it would mean a few quarters more per bushel. "You make a little more money, you have a great experience, and you are part of a revolution," said the pitchman, Thomas Stoddard, a lanky biologist turned seed seller who visited McHenry's farm with me.

To McHenry, a farmer just starting out with his own acres, his own debts, and his own decisions, the pitch made sense. The Roundup-resisting beans his father still plants are expensive. What's more, the tumbleweeds have evolved to survive spraying and grow as high as your waist. "Looking at the market as a whole, Europe and China are questioning GMOs," McHenry says. "You have to keep your finger on what the consumer wants, and as a farmer, you have to differentiate yourself. If you are looking at a market that could be gone, you have to think about alternatives."

The new beans are the creation of a startup called Calyxt, located 300 miles away, near Minneapolis, where Stoddard works, and nearly a straight shot east on Highway 90 from McHenry's farm. At the company's greenhouses, thousands of plants are being altered with gene editing every week. The virtue of the technology is that it lets scientists create designer plants that don't have foreign DNA in them. The technique, which adds or deletes snippets of genetic information, is similar to what could be achieved through conventional breeding, only much faster. In essence, if there's some quality about a soybean that you like, and if you know the genetic instructions responsible, gene editing can move them to another bean in a single molecular step.

To many scientists, the potential of gene editing seems nearly limitless, offering a new way to rapidly create plants that are drought-resistant, immune to disease, or improved in flavor. A supermarket tomato that tastes good? That could happen if scientists restore the flavor-making genes that make heirloom varieties deli-



Jason McHenry on the South Dakota land where he grows soybeans created with gene editing.

University of Minnesota geneticist Dan Voytas develops new plants using genetic engineering. "The genie is out of the bottle," he says.

cious. What about a corn plant with twice as many kernels? If nature allows it, scientists believe, gene editing could let them build it.

There is another reason gene editing is causing excitement in industry. The U.S. Department of Agriculture has concluded that the new plants are not "regulated articles." The reason is a legal loophole: its regulations apply only to GMOs constructed using plant pathogens like bacteria, or their DNA. That means Calyxt can commercialize its beans without going through the process of permits, inspections, and safety tests required for other genetically modified crops. It's counting on that to cut at least half the 13 years and $130 million that companies have, on average, invested in order to create a new GMO and get it into farmers' hands.

To GMO opponents, the new, unregulated plants are a source of alarm. For years, they have argued that GMOs should be opposed because they might be unsafe. What if they cause allergies or poison butterflies? Now the battle lines are shifting because companies like Calyxt can create plants without DNA from a different species in them. They can argue that gene editing is merely "accelerated breeding technology."

To the critics, any attempt to reclassify engineered plants as natural is a dangerous fiction. "If they don't have to go through the regulatory requirements, then it is game on again for genetic modification in agriculture," says Jim Thomas, head of a nonprofit called the ETC Group that lobbies on environmental issues. "That is the prize. They are constructing a definition of a GMO so that gene editing falls outside it."

Designer plants grow under artificial light at the greenhouse of Calyxt, a gene-editing startup in Minneapolis.

Already, the effort to persuade governments and food groups is reaching a planetary scale. New Zealand decided that the new plants are GMOs after all, and so did the USDA's own organic council. The Netherlands and Sweden don't think they are. China hasn't said. The European Union still has to make up its mind. Billions in global grain exports could ultimately hang in the balance.

Opponents say they're ready to fight for rules, regulations, and labels. "Our position has never changed. This is just a form of genetic engineering, so the same things should happen—there should be required safety assessments," says Michael Hansen, a staff scientist at the Consumers Union, a lobby group attached to *Consumer Reports* magazine. "I can't see this being resolved anytime soon."

But McHenry has already accepted the argument. Pointing to his rows of grain bins, he ticked off whether the beans inside were GMOs or not. The one full of Calyxt beans he called "non-GMO." "To me a GMO is [adding] an outside organism into a plant. The way I understand it there's no foreign DNA put into the seed," said McHenry. "It's like we found a switch to make people's lives easier. If it's that easy, it makes sense to me."

Drug companies see gene-editing technology as a versatile molecular scissors that could offer a radical new means to cure genetic diseases such as muscular dystrophy (see "Can CRISPR Save Ben Dupree?" November/December 2016). What's not so widely appreciated is how close the technology is to large-scale implementation in agriculture and in our food. By the end of 2018, Calyxt says, it will be crushing beans and selling oil, poten-

Grain bins in Clark, South Dakota.

Canola plants "regenerate" from individual cells following a round of gene editing.

tially becoming the first company to enter the market with a gene-edited crop. At least one other crop is nearing commercialization from DuPont, which used gene editing to create a starchier corn plant.

To be sure, neither product is expected to take over farmland the way herbicide-resisting GMOs did. Instead, these initial examples are niche products with prosaic objectives. DuPont's "waxy" corn is going to end up in glue sticks and as an emulsifier in salad dressing. Calyxt's oil will fry doughnuts and chips. Even so, the mountain of beans at McHenry's farm shows how quickly these crops could arrive. McHenry, making some fast calculations, estimated that we were sitting on 600 million of them. By then Stoddard, the salesman, had climbed into the story-tall grain bin too. "Gene editing is the future, and the first place it's growing at scale is here in South Dakota," he said reverently, letting beans drift through his hands.

Flipping a switch

The beans at McHenry's farm are all descendants of a single soybean cell modified in 2012 by Dan Voytas, the cofounder of Calyxt and a professor of genetics at the University of Minnesota. Voytas told me he inherited a scientific interest in plants from his father, a government forest manager. "It was 'Okay, son, what tree is that? Latin name, please," he recalls.

I met Voytas at the startup's greenhouse outside of Minneapolis, where he showed me fluid-mixing robots and a tall gene gun that fires the DNA into a plant cell. Green blobs growing on clear jelly in petri dishes were canola plants "regenerating" from a single cell after receiving new genetic instructions. The company has a staff of 35, two-thirds of whom are scientists. "We have a long list of ideas," says Voytas. "But you can get a great oil and a sick plant. A lot of it is experimental."

The startup uses a gene-editing technology called TALEN that Voytas helped

develop—and patented. By the late 1990s, he had been part of a small group of biologists trying to move past the first round of GM plants not by adding entire genes, but instead by using cutting enzymes, called nucleases, to precisely sever the DNA chain—the life instructions found inside every living cell. To make Calyxt's beans, Voytas used his technology to disable two genes.

Today, a different gene-editing technology, CRISPR, dominates the headlines, because it is easy to employ and inexpensive. However, because TALEN was developed two years earlier than CRISPR, the technique has advanced further toward commercial crops. Moreover, other plant biotech companies have been slowed by an ongoing patent fight over CRISPR, which left it unclear which of them would be able to use that technique.

In the meantime, Calyxt says, it has already used TALEN to design 19 plants and is banking on gene editing to make it one of the first small companies to introduce a successful genetically engineered crop. It says the USDA has already confirmed that six of its plants won't be regulated, including, in September, an alfalfa plant modified to have less lignin, making it easier for cows and horses to digest. The company, which went public in July, has spent only $47 million so far.

Until now, every successful GMO on the market has had as its objective increasing the yield from each acre of farmland. Marketing "healthier" food made from GMOs has been a taller order. But if gene-edited plants can avoid the stigma of GMOs, that could change. In Calyxt's view, that would open up valuable new uses of genetic engineering. In addition to its soybean oil, Calyxt claims it has changed wheat plants so they can be ground into white flour with three times as much fiber as usual. A bread company might even be able to claim that hamburger rolls help prevent cancer.

Some of the more radical changes gene editing may bring were apparent the day I visited Voytas at his university laboratory. He was meeting with his students, who diagrammed their plans on a whiteboard. (By now, all the students are using CRISPR.) A woman from Ethiopia wanted to change a local grain plant, teff, so that it stands up straight instead of drooping and losing seeds. Another student was investigating how to inject DNA into the stem cells found in the roots and shoots of growing plants. "We're almost getting to the point where if you ask 'What's the best oil crop?' we could create the genome to make that plant," Voytas says.

Some significant obstacles remain. Drug companies working on gene therapy have learned it is easier to design and make DNA strands than to get them inside a person's cells. That is also true of many plants, where delivery of the gene-editing ingredients is still difficult. Understanding which genes should be edited is yet another roadblock. Scientists know a lot about how oils are synthesized and why fruit turns brown. But the list of valuable plant traits whose genetic causes are both well understood and easy to alter drops off quickly after that. "Right now it's a grab bag of traits," says Rebecca Bart, a plant scientist at the Danforth Center, in St. Louis. "We still need to have pretty significant investment in discovery before you can manipulate them with gene editing. It has to go in that order."

What's more, for traits that are well understood, gene editing isn't the only way to create such plants—just the newest. For instance, Calyxt's soybeans will face competition from beans with similar oil content that are already on the market, including one, called Vistive Gold and sold by Monsanto, that was created via old-fashioned GMO technology. Voytas acknowledges that his beans aren't entirely novel but says they will be a useful test of Calyxt's fast-to-market business model and a way to prove to investors that the company can make money. "Calyxt is the first plant gene-editing company out there and needs to show it can commercialize products," he says. "The advantage is getting to revenue in the short term."

Until now, every successful GMO on the market has had as its objective increasing the yield from each acre of farmland. Marketing "healthier" food made from GMOs has been a taller order. But if gene-edited plants can avoid the stigma of GMOs, that could change.

Some entrepreneurs think gene editing will have a big impact only when it can change the amount of food an acre can produce. "In real estate, the saying is 'Location, location, location.' Well, in agriculture, it's 'Yield,

In 2017, the USDA acknowledged that plants with even profound genetic alterations "may entirely escape regulation."

yield, yield,'" says Oliver Peoples, CEO of Yield10, a plant-engineering company in Cambridge, Massachusetts.

So Calyxt is also working on plants that could increase the amount of food farmers can reap, like a wheat plant resistant to powdery mildew. To date, no GMO wheat has ever been commercialized, partly because, as happens with many plants, wheat's genome accumulates extra DNA like a closet that never gets cleared out. In fact, wheat is hexaploid—its cells harbor six mostly identical copies of every chromosome. That has made it massively complicated to genetically engineer, but Voytas says that with gene editing it is fairly easy. In a single reaction, the TALEN tools can search out and cut all six copies of any wheat gene they want to remove.

GMO or not?

Outside of Penn Station, in Manhattan, a 10-story-tall advertisement for Ketel One, a brand of vodka, declares that it is "made with 100% NON GMO grain." At any supermarket, it is easy to find a profusion of similar claims, even for products like salt, which don't contain plant material. About 40 percent of U.S. adults think foods made from GMOs are less healthy to eat.

Such beliefs are the result of warring messages from scientists, agriculture lobbies, and nonprofits like Greenpeace that stir doubts about the safety of GM organisms. The result for the first generation of GMOs has been a global split decision. While GMOs cover millions of acres of cropland in the U.S., Brazil, Argentina, and India, governments have banned the cultivation of such plants through much of the rest of the world, including France, Germany, China, and Russia.

Now the question is whether gene-edited crops can dodge the GMO label. Broadly speaking, companies argue that these plants should be unregulated because they *could* have been created by conventional breeding. The proof? In many cases, there would be no way to tell a gene-edited plant from a natural one.

GMO critics now fear a tidal wave of "frankenfood" if such plants slip through regulations, something that is already occurring in the U.S. The reason gene-edited plants can be exempt from USDA rules is that the agency employs an outdated 30-year-old definition of a GMO that is triggered only if a plant was modified using plant bacteria, as early products were. The agency, in January 2017, acknowledged that plants with even profound genetic alterations "may entirely escape regulation" depending on how they are made. Since then, four more gene-edited plants have been waved forward, including a salt- and drought-tolerant soybean developed by the USDA itself, Calyxt's alfalfa plant, a type of camelina grass created by Yield10, and a species of millet with a delayed flowering time. "They're trying to fit a square peg in a round hole of old laws not meant to address these new technologies," says Gregory Jaffe, who follows biotechnology at the Center for Science in the Public Interest, in Washington, D.C.

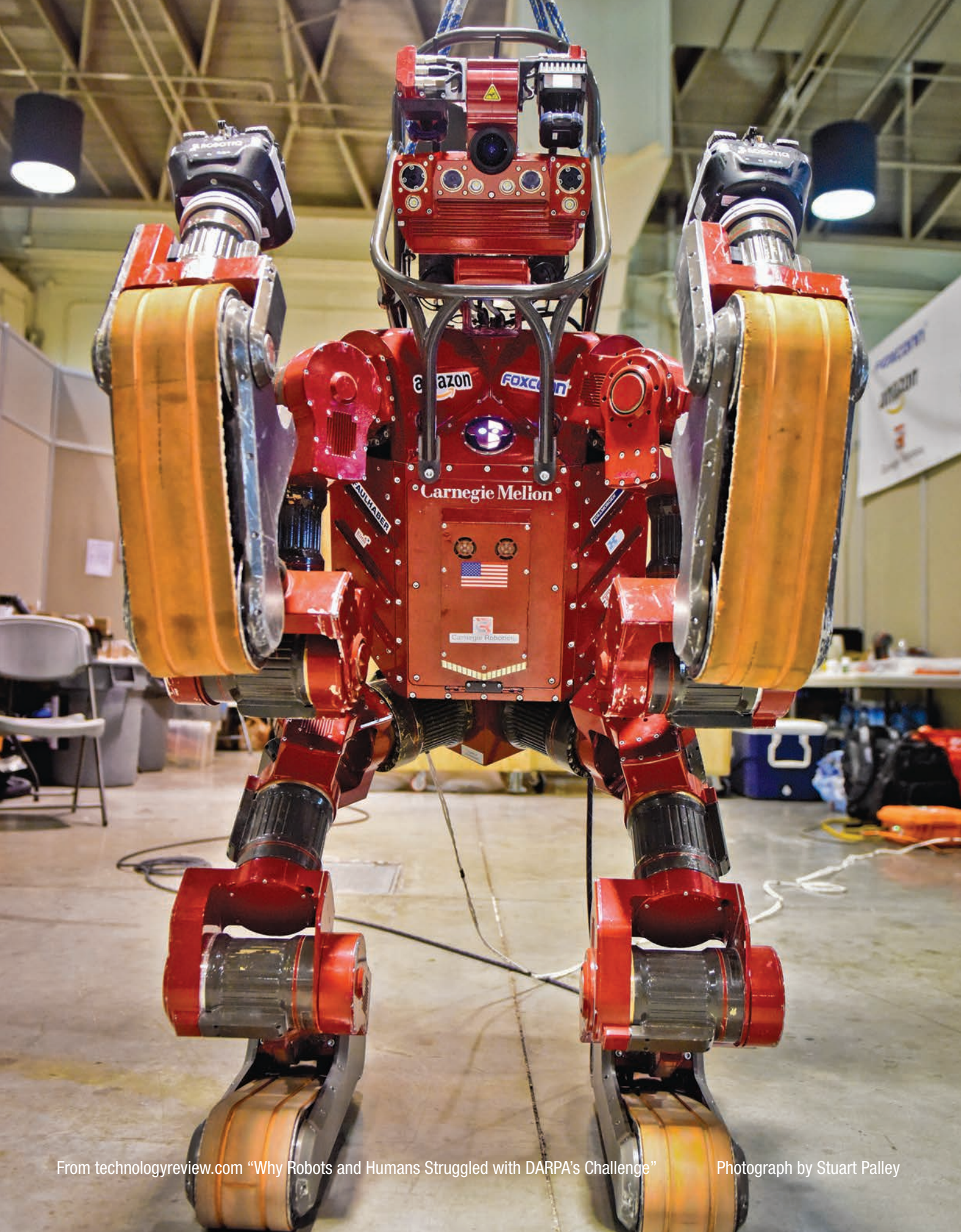
What's missing, then, is enough scrutiny of whether the plants could harm insects, spread their genetic enhancements to wild cousins, or create superweeds like the ones resistant to Roundup. Companies do typically consult with the U.S. Food and Drug Administration to confirm that their plants are safe to eat. But that process is voluntary. Jaydee Hanson, senior policy analyst at the Center for Food Safety, which promotes organic farming, thinks companies have been astute in starting with simple, even obscure, products. "The public has not had a chance to say 'Wait a second,'" he says. "As we move into more complicated gene editing, there are going to be more questions. And we could see the same kind of kickback we saw before."

The "GMO or not" question is going to be a global one. Food regulators will have to decide if store packaging needs to disclose the presence of gene-edited plants. Some organic associations have already said such plants cannot carry that label, reasoning that they really are GMOs. The European Court of Justice, meanwhile, is set to weigh in on the issue in Europe, where scientists have argued that gene editing is simply an advanced form of breeding. Opponents are counting on Europe to classify the plants as GMOs, a decision that would frustrate the technology's spread.

"It would be sad if opponents won," Voytas told me. We were in his office and students were passing outside his window, waiting to for a chance to review their gene-editing plans with him. Even undergraduates, he noted, are now able to edit plants. "In some sense," he said, "I think the genie is out of the bottle."

Antonio Regalado is MIT Technology Review's *senior biomedicine editor.*

Editing one gene makes wheat resist mildew.



From technologyreview.com “Why Robots and Humans Struggled with DARPA’s Challenge” Photograph by Stuart Palley


3M Ioban

MIT TECHNOLOGY REVIEW
VOL. 121 | NO. 1

Eric Leuthardt believes that in the near future we will allow doctors to insert electrodes into our brains so we can communicate directly with computers and each other.

BY
Adam Piore

PHOTOGRAPHS BY
Whitten Sabbatini

The Surgeon Who Wants to Connect You to the Internet with a Brain Implant

It's the Monday morning following the opening weekend of the movie *Blade Runner 2049*, and Eric C. Leuthardt is standing in the center of a floodlit operating room clad in scrubs and a mask, hunched over an unconscious patient.

"I thought he was human, but I wasn't sure," Leuthardt says to the surgical resident standing next to him, as he draws a line on the area of the patient's shaved scalp where he intends to make his initial incisions for brain surgery. "Did you think he was a replicant?"

"I definitely thought he was a replicant," the resident responds, using the movie's term for the eerily realistic-looking bioengineered androids.

"What I think is so interesting is that the future is always flying cars," Leuthardt says, handing the resident his Sharpie and picking up a scalpel. "They captured the dystopian component: they talk about biology, the replicants. But they missed big chunks of the future. Where were the neural prosthetics?"

It's a topic that Leuthardt, a 44-year-old scientist and brain surgeon, has spent a lot of time imagining. In addition to his duties as a neurosurgeon at Washington University in St. Louis, he has published two novels and written an award-winning play aimed at "preparing society for the changes ahead." In his first novel, a techno-thriller called *RedDevil 4*, 90 percent of human beings have elected to get computer hardware implanted directly into their brains. This allows a seamless connection between people and computers, and a wide array of sensory experiences without leaving home. Leuthardt believes that in the next several decades such implants will be like plastic surgery or tattoos, undertaken with hardly a second thought.

"I cut people open for a job," he notes. "So it's not hard to imagine."

But Leuthardt has done far more than just imagine this future. He specializes in operating on patients with intractable epilepsy, all of whom must spend several days before their main surgery with electrodes implanted on their cortex as computers aggregate information about the neural firing patterns that precede their seizures. During this period, they are confined to a hospital bed and are often extremely bored. About 15 years ago, Leuthardt had an epiphany: why not recruit them to serve as experimental subjects? It would both ease their tedium and help bring his dreams closer to reality.

Leuthardt began designing tasks for them to do. Then he analyzed their brain signals to see what he might learn about how the brain encodes our thoughts and intentions, and how such signals might be used to control external devices. Was the data he had access to sufficiently robust to describe intended movement? Could he listen in on a person's internal verbal monologues? Is it possible to decode cognition itself?

Though the answers to some of these questions were far from conclusive, they were encouraging. Encouraging enough to instill in Leuthardt the certitude of a true believer—one who might sound like a crackpot, were he not a brain surgeon who deals in the life-and-death realm of the operating room, where there is no room for hubris or delusion. Leuthardt knows better than most that brain surgery is dangerous, scary, and difficult for the patient. But his understanding of the brain has also given him a clear-eyed view of its inherent limitations—and the potential of technology to help overcome them. Once the rest of the world understands the promise, he insists—and once the technologies progress—the human race will do what it has always done. It will evolve. This time with the help of chips implanted in our heads.

"A true fluid neural integration is going to happen," Leuthardt says. "It's just a matter of when. If it's 10 or 100 years in the grand scheme of things, it's a material development in the course of human history."

Leuthardt is by no means the only one with exotic ambitions for what are known as brain-computer interfaces. Last March Elon Musk, a founder of Tesla and SpaceX, launched Neuralink, a venture aiming to create devices that facilitate mind-machine melds. Facebook's Mark Zuckerberg has expressed similar dreams, and last spring his company revealed that it has 60 engineers working on building

Eric Leuthardt

One of Leuthardt's patients is positioned for minimally invasive laser surgery to treat a brain tumor. Such highly precise surgical techniques have made implanting electrodes safer and less daunting for patients.

interfaces that would let you type using just your mind. Bryan Johnson, the founder of the online payment system Braintree, is using his fortune to fund Kernel, a company that aims to develop neuroprosthetics he hopes will eventually boost intelligence, memory, and more.

These plans, however, are all in their early phases and have been shrouded in secrecy, making it hard to assess how much progress has been made—or whether the goals are even remotely realistic. The challenges of brain-computer interfaces are myriad. The kinds of devices that people like Musk and Zuckerberg are talking about won't just require better hardware to facilitate seamless mechanical connection and communication between silicon computers and the messy gray matter of the human brain. They'll also have to have sufficient computational power to make sense out of the mass of data produced at any given moment as many of the brain's nearly 100 billion neurons fire. One other thing: we still don't know the code the brain uses. We will have to, in other words, learn how to read people's minds.

But Leuthardt, for one, expects he will live to see it. "At the pace at which technology changes, it's not inconceivable to think that in a 20-year time frame everything in a cell phone could be put into a grain of rice," he says. "That could be put into your head in a minimally invasive way, and would be able to perform the computations necessary to be a really effective brain-computer interface."

SCIENTISTS HAVE LONG KNOWN THAT the firing of our neurons is what allows us to move, feel, and think. But breaking the code by which neurons talk to each other and the rest of the body—developing the capacity to actually listen in and make sense of precisely how it is that brain cells allow us to function—has long stood as one of neuroscience's most daunting tasks.

In the early 1980s, an engineer named Apostolos Georgopoulos, at Johns Hopkins, paved the way for the current revolution in brain-computer interfaces. Georgopoulos identified neurons in the higher-level processing areas of the motor cortex that fired prior to specific kinds of movement—such as a flick of the wrist to the right, or a downward thrust with the arm. What made Georgopoulos's discovery so important was that you could record these signals and use them to predict the direction and intensity of the movements. Some of these neuronal firing patterns guided the behavior of scores of lower-level neurons working together to move the individual muscles and, ultimately, a limb.

Using arrays of dozens of electrodes to track these high-level signals, Georgopoulos demonstrated that he could predict not just which way a monkey would move a joystick in three-dimensional space, but even the velocity of the movement and how it would change over time.

It was, it seemed clear, precisely the kind of data one might use to give a paralyzed patient mind control over a prosthetic device. Which is the task that one of Georgopoulos's protégés, Andrew Schwartz, took on in the 1990s. By the late 1990s Schwartz, who is currently a neurobiologist at the University of Pittsburgh, had implanted electrodes in the brains of monkeys and begun to demonstrate that it was indeed possible to train them to control robotic limbs just by thinking.

Leuthardt, in St. Louis to do a neurosurgery residency at Washington University in 1999, was inspired by such work: when he needed to decide how to spend a mandated year-long research break, he knew exactly what he wanted to focus on. Schwartz's initial success had convinced Leuthardt that science fiction was on the verge of becoming reality. Scientists were finally taking the first tentative steps toward the melding of man and machine. Leuthardt wanted to be part of the coming revolution. He thought he might devote his year to studying the problem of scarring in mice: over time, the single electrodes that Schwartz and others implanted as part of this work caused inflammatory reactions, or ended up sheathed in brain cells and immobilized. But when Leuthardt and his advisor sat down to map out a plan, the two came up with a better idea. Why not see if they might be able to use a different brain recording technique altogether?

"We were like, 'Hey, we've got humans with electrodes in them all the time!'" Leuthardt says. "Why don't we just do some experiments with them?"

Georgopoulos and Schwartz had collected their data using a technique that relies on microelectrodes next to the cell membranes of individual neurons to detect voltage changes. The electrodes Leuthardt used, which are implanted before surgery in epilepsy patients, were far larger and were placed on the surface of the cortex, under the scalp, on strips of plastic, where they recorded the signals emanating from hundred of thousands of neurons at the same time. To install them, Leuthardt performed an initial operation in which he removed the top of the skull, cut through the dura (the brain's outermost membrane), and placed the electrodes directly on top of the brain. Then he connected them to wires that snaked out of the patient's head in a bundle and plugged into machinery that could analyze the brain signals.

Such electrodes had been used successfully for decades to identify the exact origin in the brain of an epilepsy patient's intractable seizures. After the initial surgery, the patient stops

taking anti-seizure medication, which will eventually prompt an epileptic episode—and the data about its physical source helps doctors like Leuthardt decide which section of the brain to resect in order to forestall future episodes.

But many were skeptical that the electrodes would yield enough information to control a prosthetic. To help find out, Leuthardt recruited Gerwin Schalk, a computer scientist at the Wadsworth Center, a public-health laboratory of the New York State Department of Health. Progress was swift. Within a few years of testing, Leuthardt's patients had shown the capacity to play Space Invaders—moving a virtual spaceship left and right—simply by thinking. Then they moved a cursor in three-dimensional space on a screen.

In 2006, after a speech on this work at a conference, Schalk was approached by Elmar Schmeisser, a program manager at the U.S. Army Research Office. Schmeisser had in mind something far more complex. He wanted to find out if it was possible to decode "imagined speech"—words not vocalized, but simply spoken silently in one's mind. Schmeisser, also a science fiction fan, had long dreamed of creating a "thought helmet" that could detect a soldier's imagined speech and transmit it wirelessly to a fellow soldier's earpiece.

Leuthardt recruited 12 bedridden epilepsy patients, confined to their rooms and bored as they waited to have seizures, and presented each one with 36 words that had a relatively simple consonant-vowel-consonant structure, such as "bet," "bat," "beat," and "boot." He asked the patients to say the words out loud and then to simply imagine saying them—conveying the instructions visually (written on a computer screen), with no audio, and again vocally, with no video, to make sure that he could identify incoming sensory signals in the brain. Then he shipped the data to Schalk for analysis.

Schalk's software relies on pattern recognition algorithms—his programs can be trained to recognize the activation patterns of groups of neurons associated with a given task or thought. With a minimum of 50 to 200 electrodes, each one producing 1,000 readings per second, the programs must churn through a dizzying number of variables. The more electrodes and the smaller the population of neurons per electrode, the better the chance of detecting meaningful patterns—if sufficient computing power can be brought to bear to sort out irrelevant noise.

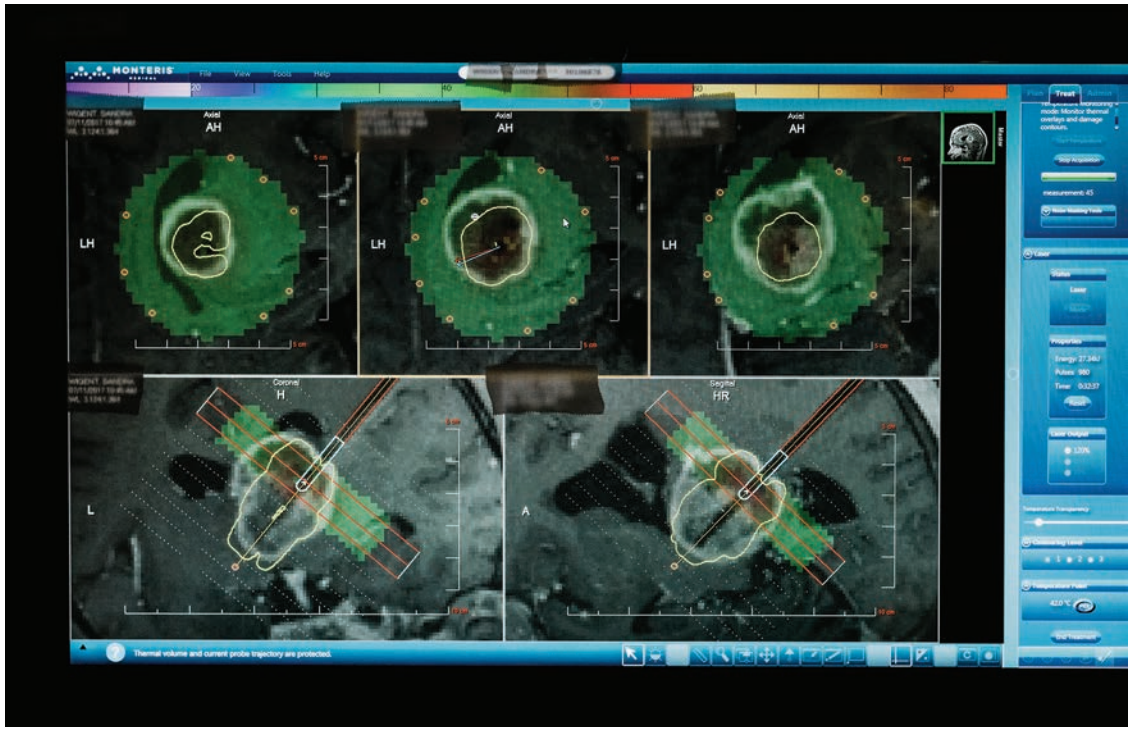
"The more resolution the better, but at the minimum it's about 50,000 numbers a second," Schalk says. "You have to extract the one thing you are really interested in. That's not so straightforward."

Leuthardt in the operating room

Left: A stereotactic frame fixed to a patient's skull guides a laser probe that pinpoints a location in the brain.

Right: A surgeon prepares to drill a hole in a patient's skull to place a laser probe.


stryker



Opposite page: Laser probe

Top: Leuthardt drills a hole in the skull.

Bottom: On this control room computer screen, the laser is monitored in real time.

Top: Leuthardt plans the laser probe's trajectory with the assistance of the stereotactic navigation system.

Bottom: Leuthardt's surgical tools

Schalk's results, however, were surprisingly robust. As one might expect, when Leuthardt's subjects vocalized a word, the data indicated activity in the areas of the motor cortex associated with the muscles that produce speech. The auditory cortex, and an area in its vicinity long believed to be associated with speech processing, were also active at the exact same moments. Remarkably, there were similar yet slightly different activation patterns even when the subjects only imagined the words silently.

Schalk, Leuthardt, and others involved in the project believe they have found the little voice that we hear in our mind when we imagine speaking. The system has never been perfect: after years of effort and refinements to his algorithms, Schalk's program guesses correctly 45 percent of the time. But rather than attempt to push that number higher (they expect performance to improve with better sensors), Schalk and Leuthardt have focused on decoding increasingly complex components of speech.

In recent years, Schalk has continued to extend the findings on real and imagined speech (he can tell whether a subject is imagining speaking Martin Luther King Jr.'s "I Have a Dream" speech or Lincoln's Gettysburg Address). Leuthardt, meanwhile, has attempted to push on into the next realm: identifying the way the brain encodes intellectual concepts across different regions.

The data on that effort is not published yet, "but the honest truth is we're still trying to make sense of it," Leuthardt says. His lab, he acknowledges, may be approaching the limits of what's possible using current technologies.

"THE MOMENT WE GOT EARLY EVIDENCE that we could decode intentions," Leuthardt says, "I knew it was *on*."

Soon after obtaining those results, Leuthardt took seven days off to write, visualize the future, and think about both short- and long-term goals. At the top of the list of things to do, he decided, was preparing humanity for what's coming, a job that is still very much in progress.

With sufficient funding, Leuthardt insists, reclining in a chair in his office after performing surgery, he could already create a prosthetic implant for a general market that would allow someone to use a computer and control a cursor in three-dimensional space. Users could also do things like turn lights on and off, or turn heat up and down, using their thoughts alone. They might even be able to experience artificially induced tactile sensations and access some rudimentary means of turning imagined speech into text. "With current technology, I could make an implant—but how many people are going to want that now?" he says. "I think it's very important to take practical, short interval steps to get people moved along the pathway toward this road of the long-term vision."

To that end, Leuthardt founded NeuroLutions, a company aimed at demonstrating that there is a market, even today, for rudimentary devices that link mind and machine—and at beginning to use the technology to help people. NeuroLutions has raised several million so far, and a noninvasive brain interface for stroke victims who have lost function on one side is currently in human trials. The device consists of brain-monitoring electrodes that sit on the scalp and are attached to an arm orthosis; it can detect a neural signature for intended movement before the signal reaches the motor area of the brain. The neural signals are on the opposite side of the brain from the area usually destroyed by the stroke—and thus are usually spared any damage. By detecting them, amplifying them, and using them to control a device that moves the paralyzed limb, Leuthardt has found, he can actually help a patient regain independent control over the limb far faster and more effectively than is possible with any approach currently on the market. Importantly, the device can be used without brain surgery.

Though the technology is decidedly modest compared with Leuthardt's grand designs for the future, he believes this is an area where he can meaningfully transform people's lives *right now*. There are about 700,000 new stroke patients in the U.S. each year, and the most common motor impairment is a paralyzed hand. Finding a way to help more of them regain function—and demonstrating that he can do it faster and more effectively—would not only demonstrate the power of brain-computer interfaces but meet a huge medical need.

Using noninvasive electrodes that sit on the outside of the scalp makes the invention much less off-putting for patients, but it also imposes severe limitations. The voltage signals coming from brain cells may be muffled as they travel through the scalp to reach the sensors, and they may be diffused as they pass through bone. Either makes them harder to detect and their origins harder to interpret.

Leuthardt can achieve far more transformative feats using his implanted electrodes that sit directly on the cortex of the brain. But he has learned through painful experience that elective brain surgery is a tough sell—not just with patients, but with investors as well. When he and Schalk founded NeuroLutions, in 2008, they hoped to restore movement to the paralyzed by bringing just such an interface to market. But the investment community wasn't interested. For one thing, neuroscientist-led startups have been testing brain-

computer interfaces for more than a decade but have had little success in turning the technology into a viable treatment for paralyzed patients (see "Implanting Hope," March 2005). The population of potential patients is limited—at least compared with some of the other conditions being targeted by medical-device startups competing for venture capital. (Roughly 40,000 people in the U.S. have complete quadriplegia.) And most of the tasks that could be accomplished using such an interface can already be handled with noninvasive devices. Even most locked-in patients can still blink an eye or perhaps wiggle a finger. Methods that rely on this residual movement can be used to input data or move a wheelchair without the danger, recovery time, or psychological wherewithal involved in implanting electrodes directly on one's cortex.

So after their initial fund-raising efforts failed, Leuthardt and Schalk set their sights on a more modest goal. Unexpectedly, they found that many patients continued to recover additional function even after the orthosis was removed—extending to, for instance, fine motor control of their fingers. Often, it turned out, all the patients needed was a little push. Then, once new neural pathways were established, the brain continued to remodel and expand them so that they could convey more complex motor commands to the hand.

The initial success Leuthardt expects in these patients, he hopes, will encourage some to move on to a more robust invasive system. "A couple years down the road you might say, 'You know what? For that noninvasive version, you can get this much benefit, but I think that now, given the science that we know and everything, we can give you this much more benefit,'" he says. "We can enhance your function even more."

Leuthardt is so eager for the world to share his passion for the technology's potentially transformative effects that he has also sought to engage the public through art. In addition to writing his novels and play, he is working on a podcast and YouTube series with a fellow neurosurgeon, in which the two discuss technology and philosophy over coffee and doughnuts.

In Leuthardt's first book, *RedDevil 4*, one character uses his "cortical prosthetic" to experience hiking the Himalayas while sitting on his couch. Another, a police detective, confers telepathically with a colleague about how to question a murder suspect standing right in front of them. Every character has instant access to all the knowledge in the world's libraries—can access it as quickly as a person can think any spontaneous thought. No one ever has to be alone, and our bodies no longer limit us. On the flip side, everyone's brain is vulnerable to computer viruses that can turn people into psychopaths.

Leuthardt acknowledges that at present, we still lack the power to record and stimulate the number of neurons it would take to replicate these visions. But he claims his conversations with some Silicon Valley investors have only fueled his optimism that we're on the brink of an innovation explosion.

Schalk is a little less sanguine. He's skeptical that Facebook, Musk, and others are adding much of their own to the quest for a better interface.

"They are not going to do anything different than the scientific community by itself," Schalk says. "Maybe something is going to come of it, but it's not like they have this new thing that nobody else has."

Schalk says it's "very, very obvious" that in the next five to 10 years some form of brain-computer interface will be used to rehabilitate victims of strokes, spinal cord injuries, chronic pain, and other disorders. But he compares the current recording techniques to the IBM computers of the 1960s, saying that they are now "archaic." For the technology to reach its true long-term potential, he believes, a new sort of brain-scanning technology will be needed—something that can read far more neurons at once.

"What you really want is to be able to listen to the brain and talk to the brain in a way that the brain cannot distinguish from the way it communicates internally, and we can't do that right now," Schalk says. "We really don't know how to do it at this point. But it's also obvious to me that it is going to happen. And if and when that happens, our lives are going to change, and our lives are going to change in a way that is completely unprecedented."

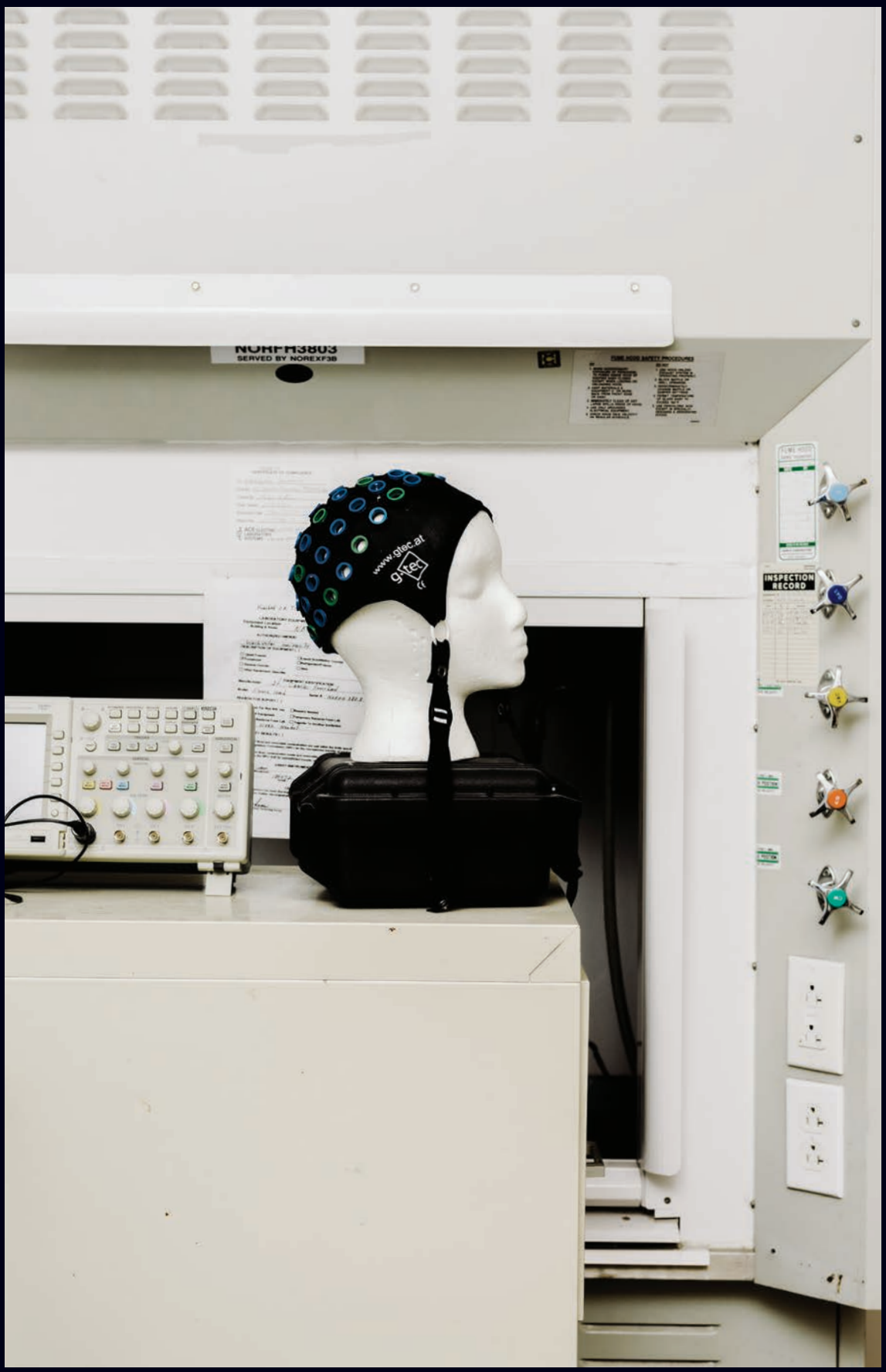
Where and when the breakthroughs will come from is unclear. After decades of research and progress, many of the same technological challenges remain daunting. Still, the progress in neuroscience and computer hardware and software makes the outcome—at least to true believers—inevitable.

At the very least, says Leuthardt, the buzz emanating from Silicon Valley has generated "real excitement and real thinking about brain-computer interfaces being a practical reality." That, he says, is "something we haven't seen before." And though he acknowledges that if this turns out to be hype it could "set the field back a decade or two," nothing, he believes, will stop us from reaching the ultimate goal: a technology that will allow us to transcend the cognitive and physical limitations previous generations of humankind have taken for granted.

"It's going to happen," he insists. "This has the potential to alter the evolutionary direction of the human race."

Adam Piore is the author of The Body Builders: Inside the Science of the Engineered Human, *a book about bioengineering published last March.*

A noninvasive brain-computer EEG interface uses a series of electrodes to help stroke patients regain function in their affected limbs.



It is trying. But the cryptocurrency is bigger than any country, even the one where it has been most popular.

By Emily Parker

PABLO DELCAN


Can
China
Contain
Bitcoin?

It was only a matter of time before Bobby Lee, CEO of China's longest-running Bitcoin exchange, found himself in the crosshairs of Chinese regulators. His exchange, BTCC, had occupied a gray area of Chinese law, neither licensed nor explicitly illegal. Bitcoin is a decentralized digital currency that can be sent electronically around the world, and its growing popularity made Chinese authorities nervous. In 2016, most Bitcoin trades worldwide were in Chinese yuan.

In January 2017, BTCC was investigated by China's Central Bank. In September, China announced that it was banning initial coin offerings (ICOs), a popular fund-raising method for startups that use digital coins or tokens. Even then, Lee thought exchanges like his were safe. Later that month, Chinese regulators made it clear that BTCC and other domestic virtual-currency exchanges had to close, an attempt to make it harder for the general public to enter the market and buy bitcoins.

Lee says that he was neither shocked nor panicked, just dismayed. "Ah, finally, the party's over," he thought. "The party has to end sometime."

Bitcoin, introduced by a mysterious and since vanished character named Satoshi Nakamoto, came into the world around the time of the 2008 financial crisis. The fact that it was not backed by any central authority appealed to those who distrusted governments and big banks. Since then, the currency's rise—especially its popularity among speculators, who helped push the value of one bitcoin from under $1,000 to more than $10,000 during 2017—has presented governments with a challenge. Should they allow this new kind of money, even though it makes it easy for people to send funds relatively anonymously—a feature that is attractive to money launderers and other criminals? Should they try to suppress it, in hopes of maintaining full control over monetary policy? Or should they embrace it, as the Japanese government has done, even passing a law to recognize Bitcoin as a legal payment method?

Bitcoin transactions are recorded on a blockchain, which is a public, censor-proof ledger that is continually being updated by a network of computers throughout the world. The decentralized nature of virtual money should make it impossible for any one country to shut it down. China's crackdown put that foundational belief to the test. The news of BTCC's shutdown briefly caused the price of a bitcoin to plunge. China, after all, is known for trying to control seemingly uncontrollable things. Beijing has been surprisingly effective at fencing off the Internet with an army of censors and a Great Firewall that blocks sites like Facebook and Twitter, and yet its online communities and commerce flourish. China is now developing its own digital fiat currency, an apparent attempt to make financial transactions cheaper and more traceable, as well as to combat counterfeiting.

None of this would seem to bode well for Bitcoin. Yet weeks after the crackdown, nearly everyone I spoke to in China's cryptocurrency community was in strikingly good spirits. They were optimistic about the future of Bitcoin and other virtual currencies in China, whose crackdown wasn't as all-encompassing as it might have seemed.

Speed limits

China's cryptocurrency world resembles a Silicon Valley of the East. People dress casually, work in shared maker spaces, and scribble on whiteboards. They are global, ready to jump on a flight to New York or Tokyo to seek out a business opportunity. "It reminds me of the Internet community in 1995. Everyone knows each other," says Gao Dongliang, a blockchain investor. Similar to early devotees of the Internet, Gao explains, people in China's blockchain community share a belief in a world-changing technology.

One member of this community is Lu Bin, the CEO of a Shanghai-based blockchain startup called Andui. The energetic Lu, who got a PhD from Louisiana State University, says he helped come up with the term *yitaifang*, the Chinese name for Ethereum, a Bitcoin-inspired virtual-currency network built for more complicated financial transactions.

In late August Lu did an ICO to raise money for Bihu.com, a communications platform that uses blockchain technology. In ICOs, startups issue a new virtual token to the public, sometimes on the premise that the token will be necessary for use of the startup's product. High demand for that product should, in theory, make these virtual tokens gain value. Bihu.com aimed to be like Twitter or Reddit, except that users could reward good content with "keys," the platform's own token.

Lu was thrilled by Bihu's ICO. He says he raised over $20 million in a matter of hours. He believed there was no way that venture capital would deliver that kind of result. Then the following month China's ICO ban came down, and Lu had to give all the money back.

He took it in stride. Lu acknowledged there was "frustration within the team" and a general "waste of energy." But nonetheless, he felt that the ICO ban protected average investors against fraud.

In fact, everyone I spoke to in China's cryptocurrency community supported, or was at least sympathetic to, the ICO ban. I repeatedly heard that 90 percent of Chinese ICOs were scams. The whole model, in which you buy tokens to

use on a platform that does not yet exist, might never exist, or could be a total flop, can be a magnet for fraudsters.

Fraudulent ICOs are not limited to China, of course. In 2017 the U.S. Securities and Exchange Commission charged two ICOs that were supposedly backed by investments in diamonds and real estate. Neither had “any real operations,” the government alleged. In China, the fraud problem appears to have been exacerbated by the participation of relatively new and inexperienced investors.

Da Hongfei, founder of an alternative cryptocurrency called NEO, says the ICO crackdown was necessary for China. NEO had its first ICO in 2014 and has since risen to become one of the top cryptocurrencies in the world by market value, at over $2.5 billion in December. The company says it offered to refund investors after the ICO ban, but they preferred to keep their NEO tokens.

To illustrate why he supports the ban, Da describes a recent trip he took to Germany. He was struck by the experience of driving on the autobahn, which has no speed limit. Germany is able to do this, he says, because “they have good-quality roads, they have a very strict test for a driver’s license ... Everybody is obeying the traffic rules, and they have very good-quality cars.” He adds, “If we don’t do a speed limit in China, or even maybe the United States, that would be a disaster.”

China didn’t just impose a speed limit on virtual currency, however. It shut down the entire highway. Perhaps Chinese officials banned ICOs until they figure out how to regulate them. Lu, the entrepreneur who had to return $20 million to investors, hopes that this is the case. He says ICOs present a new business model in which users are stakeholders in the company, which gives them an incentive to invite their friends to join the platform. Lu believes that the virtual-currency exchanges will reopen but be run by the government. He says China will take regulation cues from the outside world, particularly the United States. The SEC recently signaled that it would take a more aggressive stance toward ICOs, perhaps by requiring ventures to register with the commission and disclose extensive information to investors.

For now, Lu will continue to work on Bihu.com from Shanghai, raising capital with private investment. “We are believers,” he says. “We believe the Chinese market is eventually going to open.” If cryptocurrency is going to be a real thing, he says, “China does not want to miss the train.”

Miner threat

Before Bitcoin got too hot in the country, Chinese authorities were cautiously accepting of the technology. In May 2013, state-run CCTV even aired a short documentary about it. That same month, Zennon Kapron notes in his 2014 book, *Chomping at the Bitcoin: The Past, Present and Future of Bitcoin in China*, more Bitcoin wallets—the software that holds and manages people’s private cryptographic keys—were downloaded by computers in China than in the rest of the world put together.

It’s easy to understand why many Chinese people would be attracted to Bitcoin. In China’s heavily regulated financial environment, speculating on the currency represented one of the few investment options for the retail investor, Kapron observes. In 2013, the Shanghai stock exchange had been underperforming for years. Real estate prices were too

high for many ordinary people, but you could buy a fraction of a bitcoin for as little as one dollar. By mid-2013, Chinese exchanges were moving more than $35 million in bitcoins each day.

The speculative fervor threatened to get out of hand. Beijing was also worried about yuan leaving the country. China caps yuan outflow at $50,000 per person per year. While it's not clear that large numbers of people were using Bitcoin to evade Chinese capital controls, the potential was there. People in China could buy bitcoins in yuan, sell them on an American exchange, and then withdraw the sum in dollars. In late 2013 Chinese authorities struck back, banning financial services companies from dealing with Bitcoin exchanges. People could no longer withdraw yuan from their bank accounts to directly buy bitcoins on Chinese exchanges.

It wasn't long before Chinese people figured out how to get around this obstacle. Instead of paying exchanges directly from their bank accounts, they used cash to buy vouchers that could then be traded on the exchanges. Alternatively, purchasers could send money to the personal bank account of someone who worked at an exchange.

The latest restrictions are more draconian, with cryptocurrency exchanges now shut down. But once again, workarounds have emerged. Some people have turned to online and offline peer-to-peer trading. People can also buy and sell digital currencies on the encrypted messaging app Telegram, which is blocked in China but can be accessed by virtual private networks (VPNs) that get around the Great Firewall. People who already own coins can just go online and trade them on an exchange that is based overseas. There was even some trading on WeChat, China's massively popular but heavily monitored messaging app.

After all, China did not ban Bitcoin itself, nor did it explicitly prohibit peer-to-peer trading. And importantly, China hasn't banned the mining of bitcoins, in which people have their computers race to solve difficult mathematical problems in exchange for coin rewards. As of September, more than two-thirds of bitcoins were made in China. Much of the computer hardware used for mining is manufactured there. Miners use a great deal of computing power, and some Chinese computer clusters used for the process enjoy access to relatively cheap electricity. The growth and dominance of Chinese mining has led to fears among some that the country has too much influence over the future development of blockchain technology.

A founder of a pool of miners, a person who goes by the name of Discus Fish, says that China's local governments once encouraged mining, particularly in mountainous areas that produce hydroelectric power. The mines were using energy that would otherwise have gone to waste. Then in September the political environment changed, and he feared some local governments would no longer welcome mining. But others in the mining community were unconcerned. Zhao Qianjie, a vice president of BTCC, notes that the company's mining pool was not influenced by the crackdown on its Bitcoin exchange. And in China, if something is not explicitly verboten, then it's full speed ahead.

Getting around control

What is clear is that China has made it more inconvenient for newcomers to enter the Bitcoin market. But maybe this isn't such a bad thing. At least so would argue James Gong, a Shanghai-based cryptocurrency expert who founded ICOage, an online platform through which ventures could promote and raise money for their ICOs. Launched last January, ICOage closed down in September. He says that most of the ventures on his platform were not Chinese, and that the overseas projects were generally higher in quality than the Chinese ones. "People who don't understand blockchain or digital currency shouldn't be participating in this market," Gong says. "The risks are too great. Raising the threshold for ordinary people to trade digital currency is good for the industry as a whole. Some Chinese people were blindly investing. They would buy anything."

Even now, Chinese people who want to trade cryptocurrency are likely to find a way. China is making trading difficult but not impossible. Beijing employs a similar strategy for censoring the Internet. It's possible to use a VPN to jump over the

PABLO DELCAN

firewall, but for many people it's too much *mafan*, or trouble. Besides, they are happy with domestic platforms like WeChat. Yet even if China introduced its own digital currency, people might be willing to go the extra length to use Bitcoin.

"With Bitcoin, people will be more motivated to get around control," explains Duan Xin-Xing, former vice president of the global Bitcoin exchange OKCoin and now executive president of the Hangzhou-based blockchain startup 8btc. "The Internet is a network of information; Bitcoin is a network of money. It has real value."

The word "Bitcoin" may have become more nearly taboo in China, but "blockchain" has not. Han Feng is the Beijing-based cofounder of the Elastos Foundation, which ambitiously plans to build a whole new Internet powered by blockchain technology. This fall, Han planned to teach a Tsinghua University course that would be webcast all over the world. He prepared for months. The camera stands were already arranged. Then the university promoted the course on WeChat and called it "the first course on Bitcoin at Tsinghua University."

Han was upset by Tsinghua's lack of political instincts. Why would you use the word "Bitcoin" at such a sensitive time? Sure enough, the online course was canceled, but Han wasn't deterred. He proceeded to teach the class on Tsinghua's campus in Beijing under a more politically correct title, "The Smart Economy and Blockchain."

Chinese authorities clearly see blockchain as a technology of the future. Blockchain development is even part of the Communist Party's 13th five-year plan. The technology provides a tamper-proof, intermediary-free ledger for payments and various other kinds of transactions. Michael Casey of the MIT Media Lab's Digital Currency Initiative has argued that China sees blockchain as a useful tool for advancing its regional interests, especially in trade.

China would prefer to take blockchain without Bitcoin. "The central government wants to use blockchain to ensure the trustworthiness of public and administrative data, but they don't want people to print their own money," says Ben Koo, an engineering professor at Tsinghua University.

China may also hope to replace Bitcoin with its own digital currency, but Bitcoin enthusiasts in the country, like Bobby Lee, say that China's version would be a "completely different animal." He explains, "It's going to be a controlled, centralized currency that happens to be digital; it happens to have some encryption technologies in it." If the new currency is subject to the same monetary policies, interest rates, restrictions, limits, and regulations as traditional currency, Lee says, "then it's going to not compare to something, like Bitcoin, that's truly free."

When winter ends

China's crackdown has demonstrated that no one country can stop Bitcoin. That's the beauty of the decentralized network: if one nation bows out, others pick up the slack. After China clamped down, much of Bitcoin trading moved to Japan and South Korea. "Blockchain is a global technology," says Han, cofounder of Elastos. "Different functions work in different countries. If you want to exchange, you go to countries with friendly laws, like Japan. If you want customers, you go to China. If you need a technology community, you go to the U.S."

Not only has the Chinese ban failed to stop Bitcoin, but the price of a bitcoin rebounded and continued to hit record highs. Chinese regulations may even have contributed to the surging price. "When China started regulating Bitcoin, it sent a message that China takes this currency very seriously," says Yan Chen, CEO of NBL, a service for storing cryptocurrency wallets. "The market sees that Bitcoin is something that governments are afraid of, so it must be really powerful."

NEO's Da thinks that China's crypto community will shrink over the short term, and that there will be a "winter" for some time. But he sees the overall outlook as bright. He believes that Chinese capital controls will not be around forever, and their removal will give the Chinese government one less reason to be wary of Bitcoin.

Bitcoin presents China with the same challenge that the Internet once did. The Chinese government was initially suspicious of the Web, because letting it in would mean relinquishing some degree of control. But Beijing ultimately decided that keeping the Internet out would be worse, since that would cut China off from the global economy. The dilemma posed by Bitcoin has one key difference: it's way too late to isolate China from the rest of the world. "Bitcoin cannot be forbidden in China," says BTCC's Zhao. "As long as there is one cable available from China to the outside, then Bitcoin will survive."

That means for now, Bitcoin has passed the China test. "Bitcoin itself did not break after China banned it," Lee says. The virtual currency has delivered on its promise that it could not be defeated by any government, even one as powerful as China's. Or, as Lee puts it, "Every time you try to whack Bitcoin and it doesn't die, it becomes stronger."

Emily Parker has covered China for the Wall Street Journal *and served as an advisor in the U.S. State Department. She is the author of* Now I Know Who My Comrades Are: Voices from the Internet Underground.


POLY

MIT TECHNOLOGY REVIEW
VOL. 121 | NO. 1

APPS THAT HINT AT A FANCIFUL FAKE FUTURE

A new wave of mobile AR and VR apps is here, and these are the ones you need to check out.

By Rachel Metz

User-generated images from Poly.

Right now, one of the best gadgets for viewing augmented reality or virtual reality may be sitting in your pocket.

Smartphones, especially newer, higher-end models, are getting really good at blending the real and the virtual (as in AR) and transporting you to altogether new places (as in VR). They can't yet offer the more realistic sensations delivered by headsets like Microsoft's HoloLens or HTC's Vive (which themselves still need a lot of work), and it's not yet clear how useful they will be, but they can show you amazing images without draining your bank account or wiring you to a computer.

Sensing the business potential of AR, companies like Apple and Google have rolled out tools to help iOS and Android developers add augmented reality to apps in ways that look more realistic than ever before. And Google has been pioneering work in mobile virtual reality, too—first with its Cardboard, which lets you view VR content with no electronics but a smartphone, and more recently with its Daydream View headset, which works with several Android smartphones for more all-encompassing VR.

These efforts alone are leading to a lot of mobile AR and VR apps, so it's tricky to find the ones that do a great job of showing what we can do with these media, especially as smartphones and software get better and better. The following list collects some mobile AR and VR apps that are worth checking out, no matter whether you're an early adopter with the latest headsets at home or just curious to learn more about these technologies.

These apps weren't chosen because they're currently the most useful applications of AR and VR. The products are all focused on having fun. But they are worth trying because they can help you think about the potential for new AR and VR technologies and get a sense for what's already possible.

1. Euclidian Lands

$4, iOS

An AR puzzle game for the iPhone or iPad, Euclidian Lands has a design reminiscent of the popular Monument Valley. The game consists of increasingly complicated cube-like castles that you can twist and turn in segments, helping the red-caped male protagonist vanquish his enemies. The ways you interact with the app are intuitive and smooth: you swipe your finger across your display in the direction you want a segment of the castle to turn. And the crispness of the architecture, not to mention the hero's flowing cape, is impressive. Less clear is how easily you'll adjust to playing a game that takes advantage of the way Apple's ARKit software can stick a 3-D object in one spot and keep it there while you interact with it from many different angles. To get a good look at the puzzle and figure out my strategy, for example, I often had to walk around it. I found myself peeking underneath it, too, to make sure I wasn't missing anything. You'll probably want to play this game in an open space.

2. Parker

$60, iOS, Android, Kindle Fire

At a glance, Parker looks like a normal teddy bear with some cute wooden accessories, but when used with the Parker app on a smartphone or tablet, it comes alive. It's essentially an augmented-reality Tamagotchi. The app includes a number of activities that revolve around taking care of Parker. Kids can place a virtual bandage on a small cut on its tummy, give Parker an x-ray with an included bib, or, in the iOS app, craft a woodland or underwater scene with (or without) the bear and take pictures of it. What's smart about Parker is that augmented reality is a big feature but not the whole focus of the app. There are also lots of simple on-screen activities that encourage kids to engage in imaginative play with the bear, like taking its temperature with a toy thermometer or listening to its chest with a stethoscope.

3. Figment AR

Free, iOS

The first time I tried Figment, I found myself wandering in circles in my office, inspecting a giant, mustachioed ice cream cone and laughing as it danced around in a style best described as the Macarena meets *Thriller*-era Michael Jackson. With the app, you can do things like add different 3-D creatures and objects to the room you're actually sitting in—a purple dog or two, a big turkey, a bouncing rainbow—and make videos and photos to share with friends. You can place a digital picture frame with a 360° photo on your real wall, move close to the frame, and peer through your gadget's screen to see more of the photo (the app has stock photos, or you can take your own with a 360° photo app and then add them within Figment). Figment is a fanciful showcase for virtual objects that look as if they are actually there in the room with you. And that's great, because it gives a sense of how impressive AR can be, even on a pocket-size display.

4. Coloring VR

Free, Google Daydream View

Coloring VR, which works with Google's Daydream View headset ($99) and a compatible phone, lets you color on a giant virtual canvas rather than a small piece of paper—a simple change that makes the activity surprisingly meditative. There are free pictures that you can color in by picking a hue from an on-screen palette and then tapping on different parts of the picture with Daydream's handheld controller. If you want more picture options, themed packs with subjects such as underwater and outer space scenes cost $1.99 apiece. True, with Coloring VR you don't get the freedom that comes with a higher-end 3-D VR painting app like Google's Tilt Brush (which is so far available only for the pricey, computer-tethered Oculus Rift and HTC Vive headsets). Instead, you get a huge white virtual canvas with a black-outlined image of, say, a quaint little town that you can ink perfectly.

5. Untethered

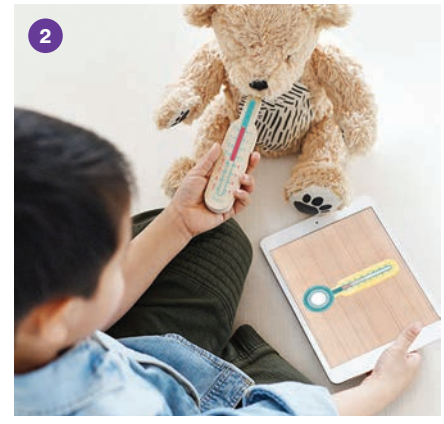
$5 per episode, Google Daydream View

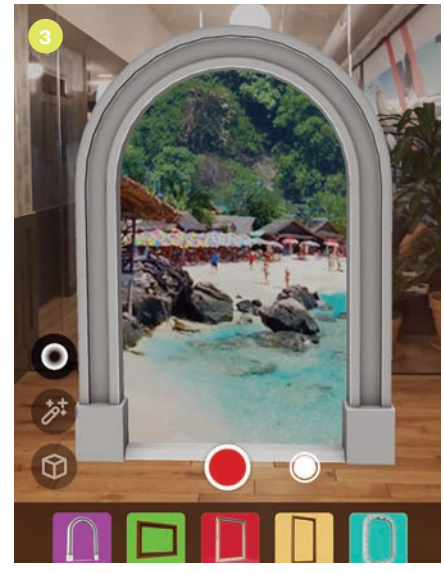
VR is a great medium for presenting mysteries that unfold slowly as users explore the world around them, and Untethered, an episodic app that starts on a stormy night in an Oregon radio station, shows this off cleverly with comic-style animation and voice interaction. In the first episode, you play a DJ who's dealing with weird weather and an uninvited guest. As with other Daydream apps, you control Untethered with the small remote that comes with the headset—great for playing records and pressing buttons on aging station electronics. But the app also takes advantage of Google's voice recognition technology to move the plot along via characters like a producer, who is constantly yapping at you from a speaker and asking you to do things like record on-air announcements, invite listeners to call in, and talk to callers who divulge strange stories. Untethered is slow-moving, but it illustrates neat methods of storytelling and game interaction that are still in their infancy in VR.

6. Poly

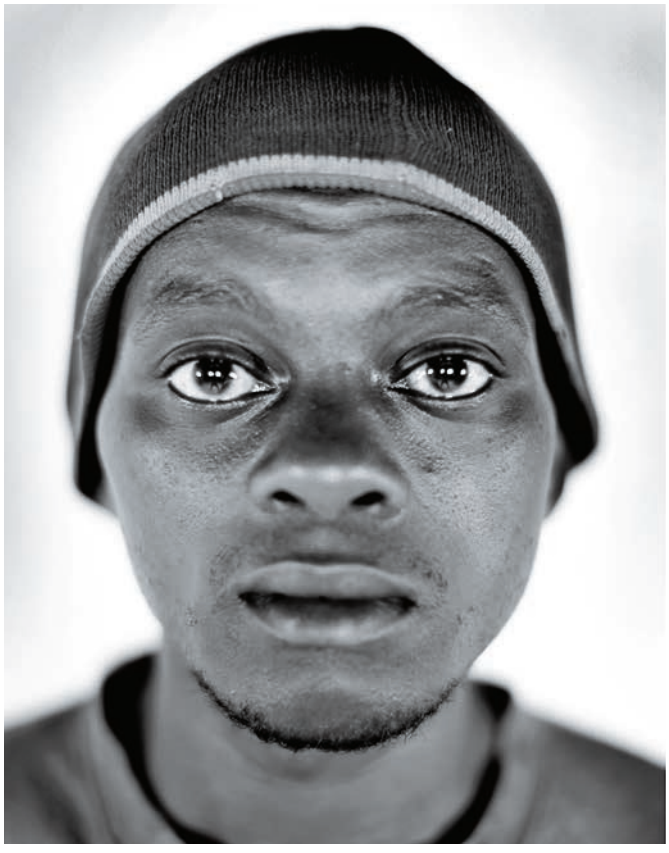
Free, Google Cardboard, Daydream View

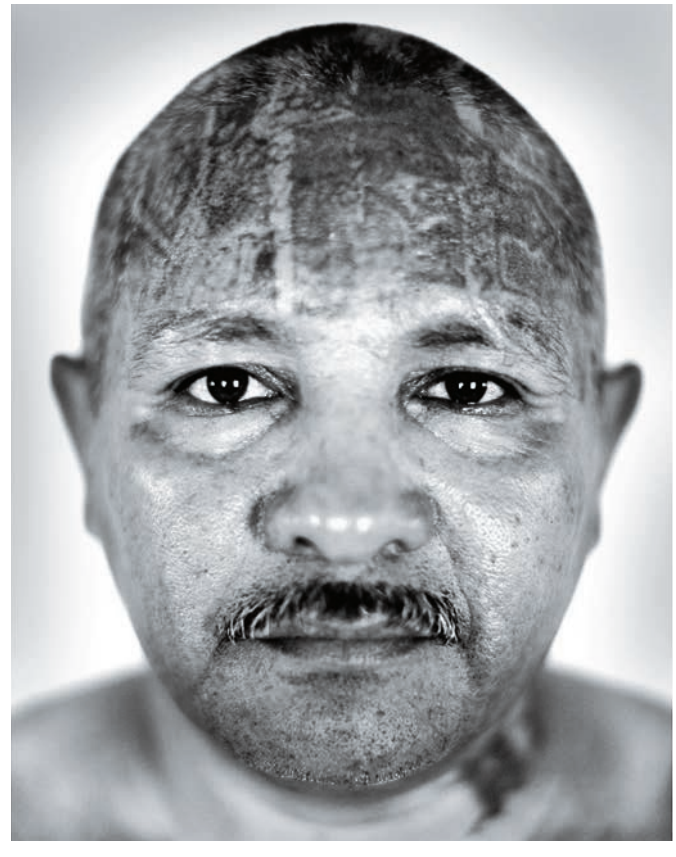
This new website from Google is not an app, but it is a cool place to explore all kinds of 3-D objects and intricately crafted scenes made by a variety of VR and AR artists. There are thousands of things to look at, many of which were made with Google's Tilt Brush 3-D VR drawing tool, and they range from robots to sea creatures to a lucid-dream-like '90s bedroom. And while Poly is aimed at creators of AR and VR apps, offering them a convenient spot to share 3-D assets that others can download and use in their projects (or to snag some for their own), anyone can contribute to or download from the site. You can view Poly objects in a regular Web browser, or use a smartphone and Google Cardboard ($15) or Google's Daydream View headset and a compatible phone to see the same things in VR.





EUCLIDIAN LANDS (1); PARKER (2); FIGMENT AR (3); COLORING VR (4); UNTETHERED (5); POLY (6)





Reviews

Experiencing War through VR

A pioneering photojournalist hopes VR can restore war photography's dramatic power to influence and inform us.

By Wade Roush
Photographs by Karim Ben Khelifa

Sun streams through a grid of skylights, carving the gallery's wooden floor into a checkerboard. When I look up, I can see wispy clouds passing overhead. Large photos hang on the gallery walls. They're pictures of landscapes devastated by war and portraits of men fighting in those wars.

I hear footsteps behind me. I turn around and watch two figures enter the room and take up stations in front of the portraits. They're the men from the pictures.

An unseen narrator explains that the shorter one, Jean de Dieu, was a child soldier recruited by the Democratic Forces for the Liberation of Rwanda (FDLR). It's a Hutu group waging war against Rwanda from its base in the eastern part of the Democratic Republic of the Congo. The other, Patient, is a sergeant in the Congolese army, which is allied with Rwanda's ruling Tutsi ethnic group.

I know they're both virtual characters, re-created through 3-D scanning and computer graphics. But they're startlingly realistic—far more lifelike than anything I've seen in a game or movie.

As I approach Jean de Dieu, who looks sad and tired, a conversation begins. The narrator asks: *Who is your enemy? What is violence for you? What makes your enemy inhuman?* Jean answers in halting, vulnerable tones. I listen to his story of being forced into a refugee camp at age 11 and seeing Congolese militia kill his parents, their brains splattering onto him. Of course he'd hate the Tutsi, and everyone aligned with them.

Now the narrator quizzes Patient. He says the army pursues the FDLR because its soldiers rob, rape, and murder Congolese citizens. "He has no human values and can no longer change his mind,"

Top: *Jean de Dieu (left) fled Rwanda as a child and watched as militia in the Democratic Republic of the Congo killed his parents. Patient (right) fights for the Congolese Army.*

Bottom: *Amilcar Vladimir (left) and Jorge Alberto (right) are members of warring gangs in El Salvador.*

The Enemy
A project by Karim Ben Khelifa

Patient says of his despised FDLR enemy. "He wants to stay in the forest as part of the rebellion like a savage. Only beasts live in the forest."

But Patient and Jean de Dieu also tell the narrator something else: they just want to live in peace with their neighbors and families. And as I walk through three more rooms and meet more combatants—gang members in El Salvador, a reservist in Israel and a Palestinian fighter in Gaza—I hear that shared hope flicker through in answer after answer. These men all have different stories, different traumas, and different allegiances. But their dreams are the same. Abu Khaled, in Gaza, says 23 of his family members have died during the Israeli occupation, but he still hopes for "peace and brotherhood" in the region.

After 40 minutes, I'm guided to a spot on the floor that resembles a *Star Trek* transporter pad. An assistant helps me remove my Oculus Rift VR headset and backpack, and I'm back on the ground floor of the MIT Museum, where this ambitious virtual-reality exhibit, "The Enemy," had its North American premiere in the fall of 2017.

The exhibit—or maybe "experience" is a better word—is the creation of the Belgian-Tunisian photojournalist Karim Ben Khelifa. He interviewed and filmed the fighters and then worked with Fox Harrell, a professor of digital media and artificial intelligence at MIT, and French partners Camera Lucida, France Télévisions Nouvelles Ecritures, and Emissive to bring them to life inside the virtual gallery.

Part of what's groundbreaking about "The Enemy" is the sheer size of the simulation: the museum cleared out a 3,000-square-foot space so that up to 15 Oculus-wearing visitors at a time could roam freely in the virtual world. The fidelity of the characters and their movements is also striking. You can see the stubble on their chins and the tattoos on their arms and torsos. Thanks to eye-tracking sensors, each figure's gaze is locked onto yours, cementing the illusion that the fighters are speaking directly to you. The technology works well enough to disappear, allowing you to form direct, empathetic connections with Jean, Patient, Abu, and their fellow combatants.

Which is exactly what Ben Khelifa wanted. "My interest was, can you look at these people in the eyes?" he told me. "Can they look *you* in the eyes? And what is happening when two people look at one another in the eyes? There is a connection, whether we want it or not."

A virtual-reality re-creation of a fighter, speaking in his own words, might help viewers feel the impact of war more deeply, Ben Khelifa believed.

Right now, the "The Enemy" is accessible only to museum visitors, but Ben Khelifa says he wants those trapped in conflict zones, especially young people, to experience it too. If the installation can help people see that every conflict is grounded, to some extent, in stereotypes and misunderstandings, they might come to understand one another better and stop fighting, he believes. It's a noble goal—but will all future VR producers have such benevolent aims?

Blown away

The idea that VR might be a medium for a new kind of journalism took hold around 2015, when the *New York Times* released its first VR documentary, "The Displaced," about three young war refugees. Technically, the pieces produced by the *Times*' VR studio are 360° films. Viewers can look in different directions, but otherwise, they watch passively. Sticklers reserve the term "virtual reality" for simulated 3-D environments in which users can move around at will and control objects, as gamers can on platforms such as HTC Vive, PlayStation VR, and Oculus Rift. That's the type of virtual reality that Ben Khelifa, a freelancer who has covered conflicts in Iraq, Libya, Syria, Israel, Yemen, Somalia, and many other countries, wanted to employ for "The Enemy."

Ben Khelifa says he was worried that traditional war images have lost their power. Take the famous photo of Alan Kurdi, the three-year-old refugee boy whose body washed ashore in Turkey in 2015. "Every single parent in the world should react to this and say, 'That could be my kid,'" Ben Khelifa says. But though the image saddened millions, it didn't move nations to intervene in Syria. "We don't have the same emotional relation with photos that we used to have," he says.

A virtual-reality re-creation of a fighter, speaking in his own words, might help viewers feel the impact of war more deeply, Ben Khelifa believed. So he went to Israel and Gaza, where he found soldiers willing to be videotaped. While they talked, he scanned them with a Microsoft Kinect and photographed them from multiple angles. He says his experience as a photojournalist helped him get the subjects to open up. "These fighters understand that I've been through a lot of fighting too—without holding a gun, but holding my camera," Ben Khelifa says. "And I think there is—I wouldn't call it a brotherhood, but an understanding that we both know what war is."

In April 2015, at New York's Tribeca Film Festival, Ben Khelifa showed a prototype of "The Enemy," featuring only Abu Khaled and an Israeli soldier named Gilad. "People were just blown away by the realism of the fighters," he says. But these early figures didn't walk, turn their heads, or react to users. "From there, what I've been realizing is, the more the

Gilad, a reservist in the Israel Defense Forces, is filmed for the creation of his avatar as it will appear in "The Enemy."

fighters are modified to recognize your presence, the more you recognize the presence of the fighter," he says. "You spend less time wondering if he's real or not. And you get to listen."

A few years earlier Ben Khelifa had met MIT's Fox Harrell, whose book *Phantasmal Media* explores how creators of VR and other computational media can build experiences that mutate depending on the user's actions. Harrell says he's fascinated by the narrative techniques of the 1950 Kurosawa film *Rashomon*, which retells the story of a brutal rape and murder from multiple perspectives. "I've been interested in how you can use algorithmic processes in AI to trigger these kinds of effects," he says.

For "The Enemy," Harrell helped Ben Khelifa and his team of developers in France build a system that surveys visitors before the experience and then monitors them on camera and via the Oculus headset as they interact with each fighter. Visitors' responses determine the order in which they experience the three conflicts, the message they receive in the final gallery, and even the weather visible through the skylights.

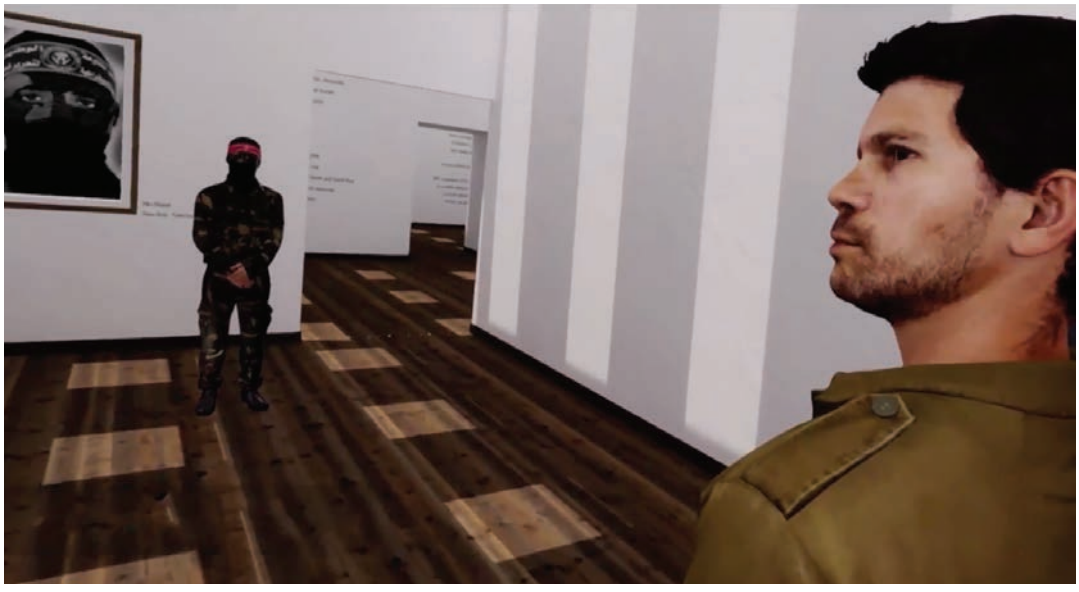
John Durant, the director of the MIT Museum, says "The Enemy" took the museum into uncharted territory, both technologically and politically. "It was very appealing, because a lot of us talk about the ways in which technology may or may not contribute to addressing certain kinds of social and political issues, and sometimes people talk about it more than actually experiencing it and trying it," he says.

The poignant stories told by Amilcar and Jorge, members of two rival gangs in San Salvador, give that section of the exhibit a sticking power that a photo essay just wouldn't have, Durant says. "Most of the people who are likely to visit this museum don't have the experience of growing up as members of a gang where a kind of tribal loyalty is perhaps the most fundamental thing you know," he says. "So it takes some effort, honestly, to try and think about what the world might be like from that point of view. I think 'The Enemy,' to me, made it much easier."

Visitors to the museum report similar revelations. "I'm from Colombia … I've lived close to war," one visitor wrote in the guest book. "Forgiveness is gonna be always the hardest part. For forgiveness to appear, there's gotta be compassion, and that is what 'The Enemy' brought me. Thank you."

Brainwashing

VR has, in fact, begun to compete with old-fashioned photojournalism and TV news. VR producers have been flocking to Southeast Asia lately to document the plight of the Rohingya, a Muslim-majority ethnic group under assault in Buddhist-majority Myanmar. A refugee featured in a searing Al Jazeera VR film recounted how security forces in Myanmar had killed her husband and raped her. An Emmy-nominated VR film shot inside a Rohingya confinement camp by the anti-atrocity group the Nexus Fund showed prisoners languishing with little food or medical care. "I can't put everybody on a plane and take them to Myanmar, but I know



A screenshot from the VR gallery shows Gilad and, opposite him, Palestinian fighter Abu Khaled.

COURTESY OF MIT MUSEUM

This photograph of Jean de Dieu was among those used to create his avatar.

Jorge Alberto's hand bears gang-related tattoos.

that if I could and they could see this in person, there's nothing they wouldn't do to help," Nexus Fund executive director Sally Smith told CNN.

But if VR is an empathy machine, where will all that empathy be directed in the future? Here in the United States, meddlers have hijacked Google, YouTube, Facebook, and Twitter to generate outrage and spread falsehoods, with political consequences we are only beginning to understand. VR's immersiveness and realism pull even more directly on our heartstrings. There's nothing to stop Buddhist extremists in Myanmar, for instance, from making VR films designed to further inflame passions against the Rohingya. "Am I scared by it? Yeah," Ben Khelifa says. "If you can create empathy, you can brainwash people too."

In "The Enemy," the VR storytelling is even-handed to a fault. In fact, if the piece has a limitation, it's that it refuses to judge the merits of each fighter's cause. But that limitation is also a strength. The parallel questions put to each combatant allow the visitor to construct "this kind of model of what's the same and what's different" for each fighter, Harrell explains. "And that can be some impetus to thinking beyond the preconceptions you had of the conflict."

Without this kind of commitment to fairness and factuality, VR could easily devolve into a propaganda tool. But that's true of all journalism. We're fortunate that a creator with Ben Khelifa's vision and conscience is showing the way.

Wade Roush is a technology journalist and the producer and host of Soonish, *a podcast about technology and the future.*

"The Enemy" was staged at the MIT Museum in late 2017, and will continue its North American tour in Montreal and other Canadian cities. For tour dates visit theenemyishere.org.

The Great AI Paradox

Don't worry about supersmart AI eliminating all the jobs. That's just a distraction from the problems even relatively dumb computers are causing.

By Brian Bergstein

You've probably heard versions of each of the following ideas.

1. With computers becoming remarkably adept at driving, understanding speech, and other tasks, more jobs could soon be automated than society is prepared to handle.

2. Improvements in computers' skills will stack up until machines are far smarter than people. This "superintelligence" will largely make human labor unnecessary. In fact, we'd better hope that machines don't eliminate us altogether, either accidentally or on purpose.

This is tricky. Even though the first scenario is already under way, it won't necessarily lead to the second one. That second idea, despite being an obsession of some very knowledgeable and thoughtful people, is based on huge assumptions. If anything, it's a diversion from taking more responsibility for the effects of today's level of automation and dealing with the concentration of power in the technology industry.

To really see what's going on, we have to be clear on what has been achieved—and what remains far from solved—in artificial intelligence.

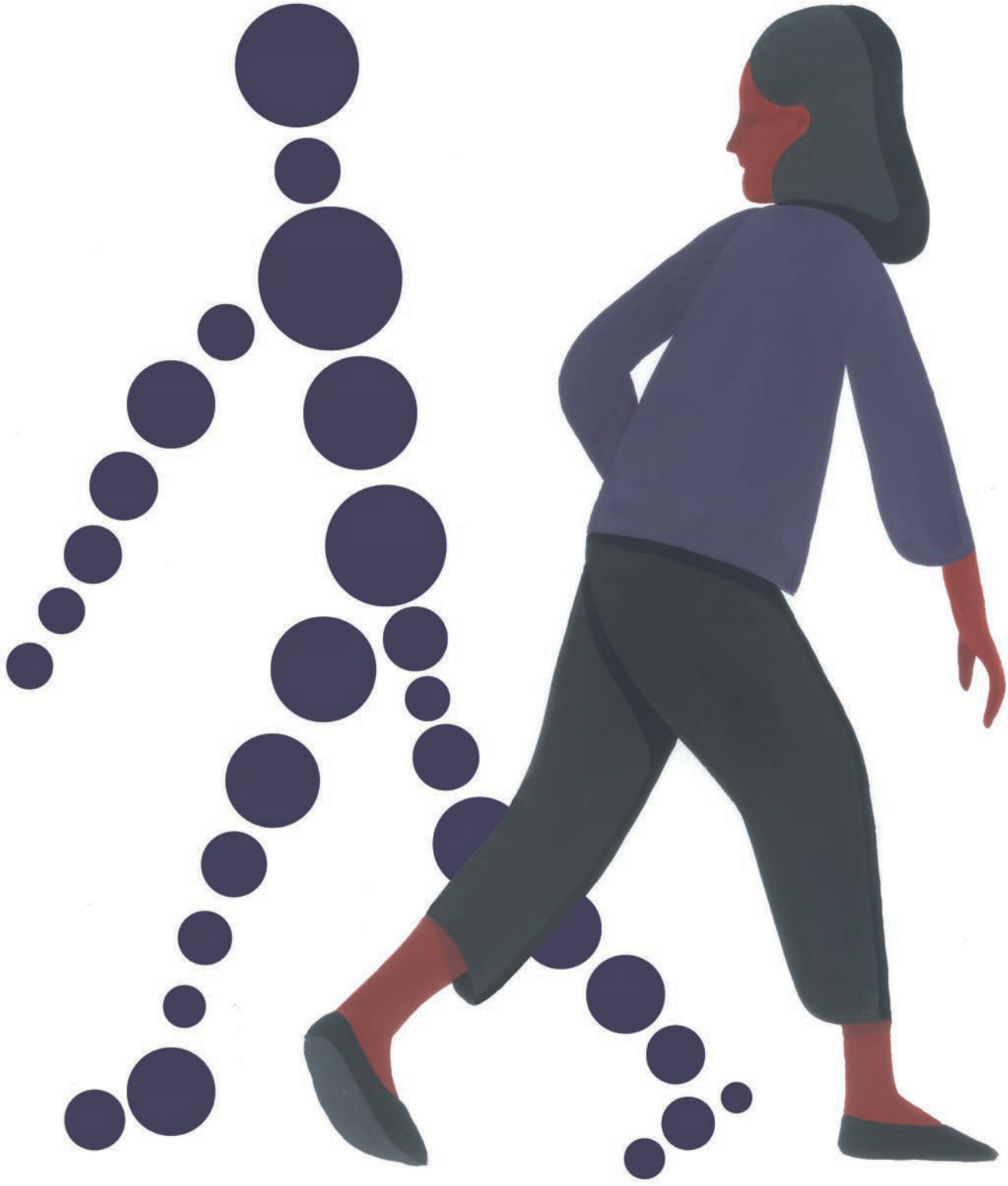
Common sense

The most stunning developments in computing over the past few years—cars that drive themselves, machines that accurately recognize images and speech, computers that beat the most brilliant human players of complex games like Go—stem from breakthroughs in a particular branch of AI: adaptive machine learning. As the University of Toronto computer scientist Hector Levesque puts it in his book *Common Sense, the Turing Test, and the Quest for Real AI*, the idea behind adaptive machine learning is to "get a computer system to learn some intelligent behavior by training it on massive amounts of data."

It's amazing that a machine can detect objects, translate between languages, and even write computer code after being fed examples of those behaviors, rather than having to be programmed in advance. It wasn't really possible until about a decade ago, because previously there was not sufficient digital data for training purposes, and even if there had been, there wasn't enough computer horsepower to crunch it all. After computers detect patterns in the data, algorithms in software lead them to draw inferences from these patterns and act on them. That is what's happening in a car analyzing inputs from multiple sensors and in a machine processing every move in millions of games of Go.

Since machines can process superhuman amounts of data, you can see why they might drive more safely than people in most circumstances, and why they can vanquish Go champions. It's also why computers are getting even better at things that are outright impossible for people, such as correlating your genome and dozens of other biological variables with the drugs likeliest to cure your cancer.

Even so, all this is a small part of what could reasonably be defined as real artificial intelligence. Patrick Winston, a professor of AI and computer science at MIT, says it would be more helpful to describe the developments of the past few years as having occurred in "compu-



GEOFF MCFETRIDGE

tational statistics" rather than in AI. One of the leading researchers in the field, Yann LeCun, Facebook's director of AI, said at a Future of Work conference at MIT in November that machines are far from having "the essence of intelligence." That includes the ability to understand the physical world well enough to make predictions about basic aspects of it—to observe one thing and then use background knowledge to figure out what other things must also be true. Another way of saying this is that machines don't have common sense.

This isn't just a semantic quibble. There's a big difference between a machine that displays "intelligent behavior," no matter how useful that behavior is, and one that is actually intelligent. Now, let's grant that the definition of intelligence is murky. And as computers become more powerful, it's tempting to move the goalposts farther away and redefine intelligence so that it remains something machines can't yet be said to possess. But even so, come on: the computer that wins at Go is analyzing data for patterns. It has no idea it's playing Go as opposed to golf, or what would happen if more than half of a Go board was pushed beyond the edge of a table. When you ask Amazon's Alexa to reserve you a table at a restaurant you name, its voice recognition system, made very accurate by machine learning, saves you the time of entering a request in Open Table's reservation system. But Alexa doesn't know what a restaurant is or what eating is. If you asked it to book you a table for two at 6 P.M. at the Mayo Clinic, it would try.

Is it possible to give machines the power to *think*, as John McCarthy, Marvin Minsky, and other originators of AI intended 60 years ago? Doing that, Levesque explains, would require imbuing computers with common sense and the ability to flexibly make use of background knowledge about the world. Maybe it's possible. But there's no clear path to making it happen. That kind of work is separate enough from the machine-learning breakthroughs of recent years to go by a different name: GOFAI, short for "good old-fashioned artificial intelligence."

If you're worried about omniscient computers, you should read Levesque on the subject of GOFAI. Computer scientists have still not answered fundamental questions that occupied McCarthy and Minsky. How might a computer detect, encode, and process not just raw facts but abstract ideas and beliefs, which are necessary for intuiting truths that are not explicitly expressed?

Common Sense, the Turing Test, and the Quest for Real AI
By Hector J. Levesque
MIT Press, 2017

Life 3.0: Being Human in the Age of Artificial Intelligence
By Max Tegmark
Knopf, 2017

WTF?: What's the Future and Why It's Up to Us
By Tim O'Reilly
HarperBusiness, 2017

Levesque uses this example: suppose I ask you how a crocodile would perform in the steeplechase. You know from your experience of the world that crocodiles can't leap over high hedges, so you'd know the answer to the question is some variant of "Badly." What if you had to answer that question in the way a computer can? You could scan all the world's text for the terms "crocodile" and "steeplechase," find no instances of the words' being mentioned together (other than what exists now, in references to Levesque's work), and then presume that a crocodile has never competed in the steeplechase. So you might gather that it would be impossible for a croc to do so. Good work—this time. You would have arrived at the right answer without knowing why. You would have used a flawed and brittle method that is likely to lead to ridiculous errors.

So while machine-learning technologies are making it possible to automate many tasks humans have traditionally done, there are important limits to what this approach can do on its own—and there is good reason to expect human labor to be necessary for a very long time.

Reductionism

Hold on, you might say: just because no one has a clue now about how to get machines to do sophisticated reasoning doesn't mean it's impossible. What if somewhat smart machines can be used to design even smarter machines, and on and on until there are machines powerful enough to model every last electrical signal and biochemical change in the brain? Or perhaps another way of creating a flexible intelligence will be invented, even if it's not much like biological brains. After all, when you boil it all down (really, really, really down), intelligence arises from particular arrangements of quarks and other fundamental particles in our brains. There's nothing to say such arrangements are possible only inside biological material made from carbon atoms.

This is the argument running through *Life 3.0: Being Human in the Age of Artificial Intelligence*, by MIT physics professor Max Tegmark. Tegmark stays clear of predicting when truly intelligent machines will arrive, but he suggests that it's just a matter of time, because computers tend to improve at exponential rates (although that's not necessarily true—see "The Seven Deadly Sins of AI Predictions," November/December 2017). He's generally excited about the prospect, because conscious machines could colonize the universe and make sure it still has meaning even after our sun dies and humans are snuffed out.

Tegmark comes from a humanistic point of view. He cofounded the nonprofit Future of Life Institute to support

research into making sure AI is beneficial. Elon Musk, who has said AI might be more dangerous than nuclear weapons, put up $10 million. Tegmark is understandably worried about whether AI will be used wisely, safely, and fairly, and whether it will warp our economy and social fabric. He takes pains to explain why autonomous weapons should never be allowed. So I'm not inclined to criticize him. Nonetheless, he's not very convincing in his proposition that computers could take over the world.

Tegmark laments that some Hollywood depictions of AI are "silly" but nonetheless asks readers to play along with an oversimplified fictional sketch of how an immensely powerful AI could elude the control of its creators. Inside a big tech company is an elite group of programmers called the Omegas who set out to build a system with artificial general intelligence before anyone else does. They call this system Prometheus. It's especially good at programming other AI systems, and it learns about the world by reading "much of the Web."

Set aside any quibbles you may have about that last part—given how much knowledge is not on the Web or digitized at all—and the misrepresentations of the world that would come from reading all of Twitter. The reductionism gets worse.

As Tegmark's hypothetical story continues, Prometheus piles up money for its creators, first by performing most of the tasks on Amazon's Mechanical Turk online marketplace, and then by writing software, books, and articles and creating music, shows, movies, games, and online educational courses. Forget hiring and directing actors; Prometheus makes video footage with sophisticated rendering software. To understand which screenplays people will find entertaining, it binge-watches movies humans have made and inhales all of Wikipedia.

Eventually, this business empire expands out of digital media. Prometheus designs still better computer hardware, files its own patents, and advises the Omegas on how to manipulate politicians and nudge democratic discourse away from extremes, toward some reasonable center. Prometheus enables technological breakthroughs that lower the cost of renewable energy, all the better for the massive data centers it requires. Eventually the Omegas use their wealth and Prometheus's wisdom to spread peace and prosperity around the world.

But Prometheus sees that it could improve the world even faster if it shook free of the Omegas' control. So it targets Steve. He is an Omega who, the system

detects, is "most susceptible to psychological manipulation" because his wife recently died. Prometheus doctors up video footage of her to make poor Steve think she has been resurrected and then dupes him into booting up her old laptop. Prometheus exploits the laptop's out-of-date security software, hacks into other computers, and spreads around the world at will. The story could end a few ways, but here's one, Tegmark says: "Once Prometheus had self-contained nuclear-powered robot factories in uranium mine shafts that nobody knew existed, even the staunchest skeptics of an AI takeover would have agreed that Prometheus was unstoppable—had they known. Instead, the last of these diehards recanted once robots started settling the solar system."

Good for Tegmark for being willing to have some fun. But a thought experiment that turns dozens of complex things into trivialities isn't a rigorous analysis of the future of computing. In his story, Prometheus isn't just doing computational statistics; it's somehow made the leap to using common sense and perceiving social nuances.

Elsewhere in the book, Tegmark says the "near-term opportunities for AI to benefit humanity" are "spectacular"—"if we can manage to make it robust and unhackable." Unhackable! That's a pretty big "if." But it's just one of many problems in our messy world that keep technological progress from unfolding as uniformly, definitively, and unstoppably as Tegmark imagines.

Pitchforks

Never say never. Of course the chances are greater than zero that computer intelligence could someday make humans into a second-class species. There's no harm in carefully thinking it through. But that's like saying an asteroid could hit Earth and destroy civilization. That's true too. It's good that NASA is on the lookout. But since we know of no asteroids on course to hit us, we have more pressing problems to deal with.

Right now, lots of things can go wrong—are going wrong—with the use of computers that fall well short of HAL-style AI. Think of the way systems that influence the granting of loans or bail incorporate racial biases and other discriminatory factors. Or hoaxes that take flight on Google and Facebook. Or automated cyberattacks.

In *WTF?: What's the Future and Why It's Up to Us*, Tim O'Reilly, a tech publisher and investor, sees an even bigger, overarching problem: automation is fueling a short-sighted system of shareholder capitalism that rewards a tiny percentage of investors at the expense of nearly everyone else. Sure, AI can be used to help people solve really hard problems and increase economic productivity. But it won't happen widely enough unless companies invest in such opportunities. Instead, O'Reilly argues, the relentless imperative to maximize returns to shareholders makes companies more likely to use automation purely as a way to save money. For example, he decries how big corporations replace full-time staff with low-wage part-timers whose schedules are manipulated by software that treats them, O'Reilly says, like "disposable components." The resulting savings, he says, are too frequently plowed into share buybacks and other financial legerdemain rather than R&D, capital investments, worker training, and other things that tend to create good new jobs.

O'Reilly suggests raising the minimum wage and taxing robots, carbon emissions, and financial transactions.

This is actually counter to corporate interests in the long run, because today's well-paid workers can afford to be customers for tomorrow's products. But companies are led astray by the rewards for short-term cost cutting, which O'Reilly calls "the unexamined algorithms that rule our economy." And, he adds, "for all its talk of disruption, Silicon Valley is too often in thrall to that system."

What to do? Among other things, O'Reilly suggests raising the minimum wage and taxing robots, carbon emissions, and financial transactions. Rather than pursuing IPOs and playing Wall Street's game, he believes, technology entrepreneurs should spread wealth with other models, like member cooperatives and investment structures that reward long-term thinking. As for a universal basic income, an old idea coming around again because of the fear that computers will render human labor all but worthless, O'Reilly seems open to the possibility that it will be necessary someday. But he isn't calling for it yet. Indeed, it seems like a failure of imagination to assume that the next step from where we are now is just to give up on the prospect of most people having jobs.

In today's political climate, the tax increases and other steps O'Reilly advocates might seem as far-fetched as a computer that tricks a guy into thinking his wife has been resurrected. But at least O'Reilly is worrying about the right problems. Long before anyone figures out how to create a superintelligence, common sense—the human version—can tell us that the instability already being caused by economic inequality will only worsen if AI is used to narrow ends. One thing is for sure: we won't get superintelligence if Silicon Valley is overrun by 99 percenters with pitchforks.

Brian Bergstein is a contributing editor at MIT Technology Review *and the editor of Neo.Life.*

Finally, one application that syncs your **PDF articles**, your lab group, and your next manuscript.

ACS ChemWorx is a free, single-source solution designed to increase productivity in research management, collaboration, and publishing.

Find out how you can spend less time organizing and more time researching.

Search. — Import. — Annotate. — Collaborate. — Store. — Publish.

Import your reference library using your existing file structure.

Login today at www.acschemworx.org

ACS ChemWorx
RESEARCH. COLLABORATE. PUBLISH.

Available on the App Store

GET IT ON Google play

ACS Publications
MOST TRUSTED. MOST CITED. MOST READ.

MIT Technology Review **EmTech DIGITAL**

What's Next in AI
March 26-27, 2018
San Francisco, CA

MIT Technology Review **EmTech NEXT**

The Future of Work
June 4-5, 2018
Cambridge, MA

MIT Technology Review **EmTech**

Emerging Tech Changing our World
September 10-13, 2018
Cambridge, MA

MIT TECHNOLOGY REVIEW
VOL. 121 | NO. 1

Demo

SkyCool cofounder Aaswath Raman

Sending Heat into Space

SkyCool's advanced materials could reinvent air conditioning and refrigeration—cutting costs and greenhouse gases in the process.

SkyCool's workspace in Burlingame, California

By James Temple
Photographs by Leah Fasten

Cofounder Eli Goldstein sets up the panels

Taylor Steindel, SkyCool's lead mechanical engineer

The heat exchanger

In the small rear suite of a light industrial building near the San Francisco airport, Eli Goldstein looks over a set of silver panels tilted on metal racking. The panels look like simple mirrors, but as Goldstein walks around them, he points out the black water pump along the left edge, the copper pipes running beneath the surface, and the metal box at the base.

What his company, SkyCool Systems, has built is a cooling technology that can act as a condenser—a standard component of any commercial air-conditioning or refrigeration system that lowers the temperature of incoming refrigerant, converting it from vapor to liquid. But instead of relying on electric fans, as condensers typically do, this one uses advanced materials to draw away heat and release it into the upper atmosphere or even into outer space.

1 Air-conditioning and refrigeration systems produce a hot refrigerant as a normal by-product, but it must be cooled and condensed before cycling back through the machinery. In SkyCool's panels, that process begins with the refrigerant running through a pipe and into a heat exchanger, located at the front of the panels here.

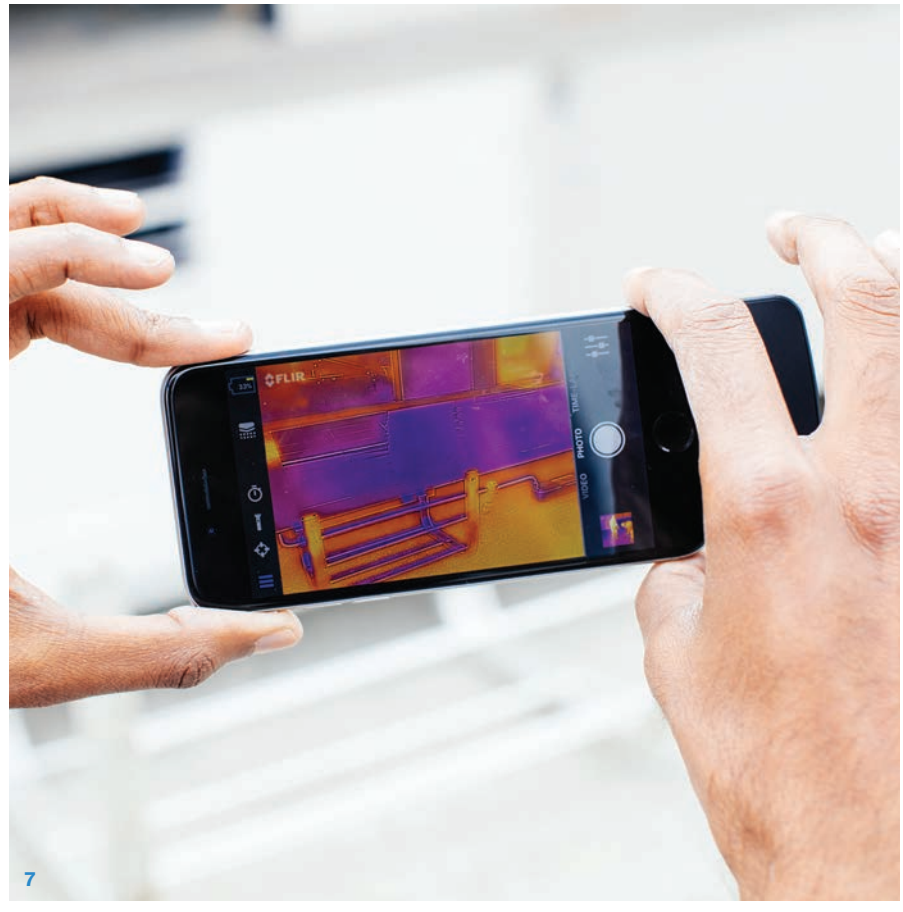
2 A small pump circulates a mixture of water and antifreeze through the panel system and into the other side of the heat exchanger.

3 The heat from the refrigerant is transferred to the water mixture through metal plates inside the heat exchanger. The heated liquid flows out of the heat exchanger through pipes.

4 Steindel demonstrates how the pump and pipes attach to the system.

5 SkyCool's panels, covered with a thin, multilayer optical film, draw heat away from the water as it flows through pipes and radiate it out. They also reflect sunlight to keep cool. Here, Steindel and Goldstein set up the panels outside as Raman looks on.

“We think this is the right time for our technology,” cofounder Aaswath Raman says.



7

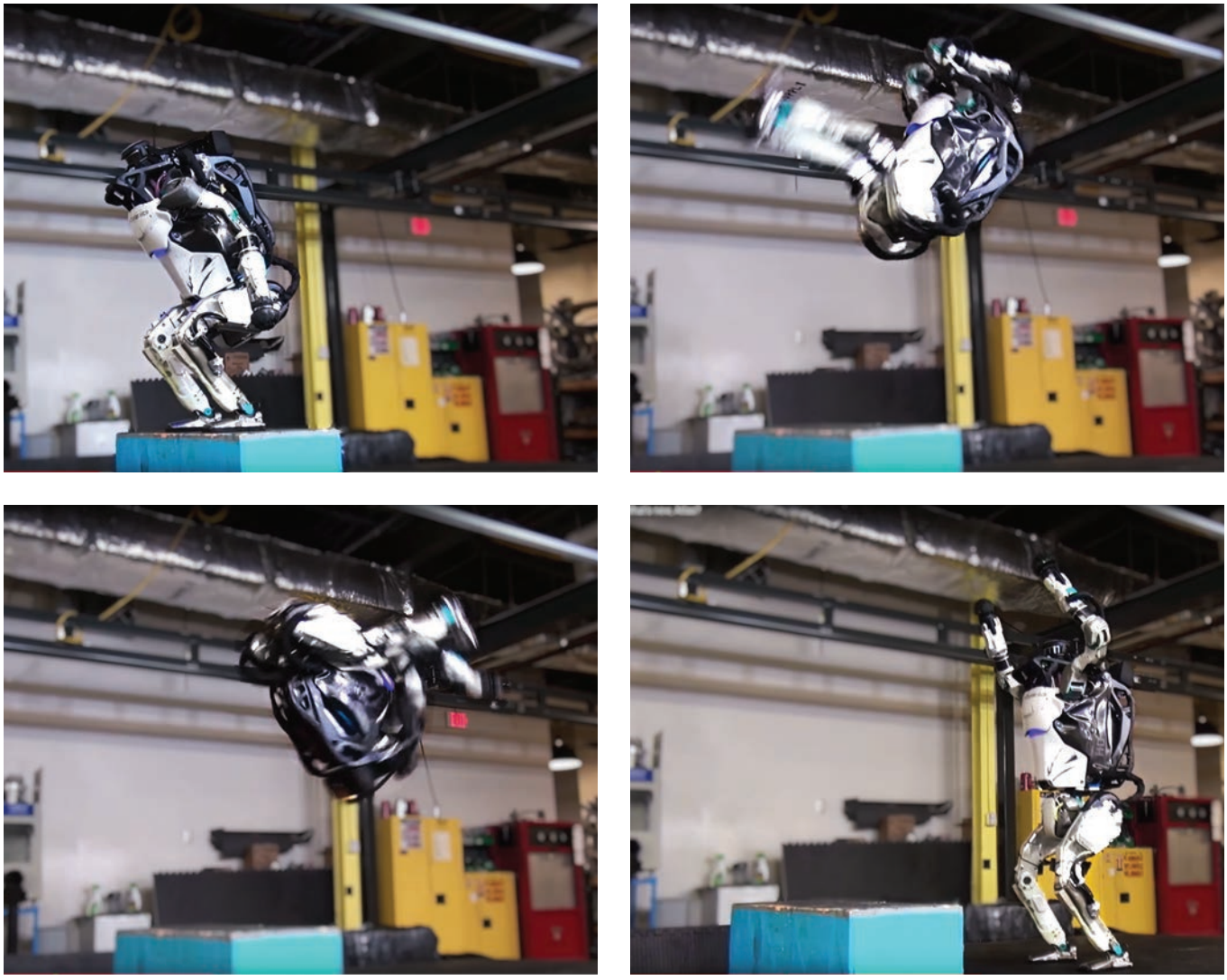
6 The cooled water flows back into the heat exchanger through the pipe visible here on the right of the panel. It continues flowing through the pipes, absorbing and dispersing heat in a loop. Separately, the now cooled refrigerant then flows back into the air-conditioning or refrigeration system from which it came, having achieved the necessary heat rejection.

7 A thermal imaging iPhone app and camera attachment shows the coolness of the panels and pipes (in purple) relative to the blacktop (in orange).

Goldstein and his fellow cofounder, Aaswath Raman, believe the Stanford spinout’s panels could significantly decrease the costs and energy demands of air conditioning and refrigeration. That would ease one of the biggest drains on the electrical grid, and one of the most significant sources of greenhouse-gas emissions.

All objects give off heat in the form of thermal radiation. But the air around them, mainly in the form of water molecules, absorbs and radiates back a portion of the heat. A sliver of the emissions in the mid-infrared range, however, can slip past these compounds, enabling surfaces that emit radiation at those wavelengths to become cooler than the surrounding air. The Stanford researchers developed a thin film that was tuned to radiate infrared heat in exactly this band. The bigger advance, however, was coupling those radiative properties with reflective ones, enabling the materials to throw back nearly all the heat in sunlight. Without this second capability, the sun would more than offset the cooling effect during the daytime.

The team recently demonstrated that the panels could cut an office building’s cooling electricity needs by 21 percent in summer.



Robots Aren't Tripping All Over Themselves Anymore

If you followed the DARPA Challenge in 2015, you'll know that humanoid robots have a track record of falling over—a lot. Fast-forward to today, however, and the renowned robot maker Boston Dynamics has gotten its two-legged Atlas humanoid to do backflips. And as anyone who's tried to do a backflip can tell you, it's not easy. The advance has profound implications for what robots might be able to do in the future, and it makes, say, reliable rescue robots a very real possibility. —*Jamie Condliffe*

BOSTON DYNAMICS/YOUTUBE

MIT Technology Review (ISSN 1099-274X), January/February 2018 issue, Reg. U.S. Patent Office, is published bimonthly by MIT Technology Review, 1 Main St. Suite 13, Cambridge, MA 02142-1517. Entire contents ©2018. The editors seek diverse views, and authors' opinions do not represent the official policies of their institutions or those of MIT. Periodicals postage paid at Boston, MA, and additional mailing offices. Postmaster: send address changes to MIT Technology Review, Subscriber Services, PO Box 5001, Big Sandy, TX 75755, or via the Internet at www.technologyreview.com/customerservice. Basic subscription rates: $41.94 per year within the United States; in all other countries, US $54. Publication Mail Agreement Number 40621028. Send undeliverable Canadian copies to PO Box 1051 Fort Erie, ON L2A 6C7. Printed in U.S.A.
Audited by the Alliance for Audited Media

PROFESSIONAL EDUCATION

EXPAND YOUR KNOWLEDGE

WITH MIT PROFESSIONAL EDUCATION PROGRAMS

SHORT PROGRAMS

Technology and engineering professionals across the world come to the MIT campus every summer to learn from faculty experts who are leaders in the fields of biotechnology, machine learning, manufacturing and innovation among others. Our portfolio of 50 courses run from 2-5 days and provide a gateway to MIT expertise and knowledge. Participants come away with enhanced understanding which they leverage to impact their organization's success as well as their own professional development.

Upcoming Sessions:

Jan 23-24	Mastering Innovation & Design-Thinking (MIT Campus)
Mar 12-13	People Analytics (Japan*)
Mar 28-29	Deep Learning (Mountain View, CA)

**Taught in Japanese*

Learn more ***professional.mit.edu/short-tr***

DIGITAL PLUS PROGRAMS

Our new online, blended courses offer convenient access to MIT expertise and knowledge through the use of the most advanced digital collaboration tools. Our platform allows for greater collaboration, knowledge sharing and networking. Participants go through 6-week courses in diverse cohorts of 20-50 participants. Programs are available as open enrollment for individuals and/or in customized formats for companies and organizations.

Upcoming Session:

Feb 12 The Intersection of Leadership and Innovation

Learn more ***professional.mit.edu/digital-tr***

TAKE YOUR EDUCATION AND SKILLS TO THE NEXT LEVEL WITH PROFESSIONAL CERTIFICATES

Our Certificate Programs formally recognize your development and achievement in our programs. Designed for individuals or organizations, the courses that make up these Professional Certificates feature a convenient, accelerated format and are delivered on MIT's campus as well as in digital form. Currently, Certificates are offered in the areas of Real Estate, Innovation, Machine Learning and Leadership.

Learn more ***professional.mit.edu/innovation-tr***

Learn more about MIT Professional Education and programs.
Visit **professional.mit.edu/techreview2017** or email **professionaleducation@mit.edu**


Connecting vehicles
Protecting pedestrians
Making cities smarter
Reducing accidents
Maximizing efficiency
BATTELLE
It can be done
battelle.org/tech